

PROPOSAL TO THE TRI-STATE WHEAT COMMISSIONS (FYs 2007-2009)

Title: Root-lesion Nematode Tolerance in Winter Wheat

Researcher: Richard Smiley, OSU-Pendleton; richard.smiley@oregonstate.edu; 541-278-4397

Cooperators: Drs. Kim Kidwell, Steve Jones, and Steve Ullrich (WSU); Kim Garland Campbell (USDA-ARS); Jim Peterson and Patrick Hayes (OSU); and Julie Nicol (CIMMYT)

Year Initiated: Current Year: July 1, 2007

Terminating Year: June 30, 2010

Justification:

A. Goal: The goal is to screen selected PNW winter wheat varieties and advanced breeding lines to quantify levels of tolerance to two species of plant-parasitic root-lesion nematodes. Studies proposed here are expected to result in an assignment of economic risk associated with growing each variety in soil infested with root-lesion nematodes. The STEEP program has been asked to fund parallel studies with spring wheat and barley. An OSU sub-contract to the USDA-ARS will fund complementary experiments to identify levels of genetic resistance capable of reducing nematode populations in high-risk fields and cropping systems.

B. Problem: Diseases may increase, decrease or remain stable in response to changes in crop management practices. Pythium root rot, Rhizoctonia root rot and root-lesion nematodes are examples of problems that become more important as cropping intensity increases. It is now recognized that at least some of the damage attributed to Pythium and Rhizoctonia is in fact confused with damage caused by root-lesion nematodes. These nematodes are especially favored by annual cropping systems in both tilled and direct-drill systems. They also thrive in winter wheat-summer fallow systems (cultivated or chem-fallow) especially where 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 having a lengthy over-wintering green bridge are functionally equivalent to annual cropping. These nematodes burrow through and disrupt the root epidermis and cortex, causing root pruning and opening root tissues to attack by fungal pathogens. Roots damaged by nematodes are unable to extract all available soil water and nutrients, leading to premature onset of plant stress at times when non-parasitized plants would continue to grow and mature normally. General production trends are for an increasing prevalence of conservation farming systems. For example, previously cultivated winter wheat-summer fallow fields are increasingly fallowed chemically and some are being converted to direct-drill annual spring crops. About 10% of dryland spring grains in Oregon and Washington are now planted without tillage, with percentages of 20 to 34% in four major cereal-producing counties. The trend toward more spring crops may become accelerated in response to incentives associated with the developing biofuels industry.

A survey of seven northeast and north-central Oregon counties and four east-central and south-central Washington counties during 1999 and 2000 showed that more than 40% of fields planted annually were infested by high populations of the root-lesion nematodes *Pratylenchus neglectus* and/or *P. thornei* (1). Populations as high as 16,000/lb of soil were detected and there was no pattern with respect to rainfall region. Populations greater than the economic threshold level of 900/lb of soil can reduce intolerant wheat yields as much as 50%. During the initial survey low populations were generally found in winter wheat-

summer fallow rotations. However, deeper sampling depths during 2005 and 2006 showed that the earlier survey greatly underestimated populations in winter wheat-summer fallow rotations and, therefore, the overall proportion of all fields with high nematode populations. The shallow soil sampling depth used earlier favored detection of high populations in annual crop fields, whereas peak populations in wheat-fallow rotations have now been found to occur as deep as two or three feet. Up to 60% of PNW fields are now thought to harbor high populations of these nematodes. Yield constraints may occur wherever high population densities occur. During 1999, for instance, yield of winter wheat (cv 'Madsen') was negatively correlated with the population of *P. neglectus* in a long-term replicated crop rotation and tillage management experiment near Pilot Rock, Oregon (Fig. 1).

Most crop species adapted to dryland PNW environments vary in levels of tolerance and resistance to these nematode species. Tolerance and resistance 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 studied in nurseries in highly infested fields. Also, when roots are invaded, nematodes multiply rapidly in susceptible varieties but not in highly resistant varieties. Levels of plant resistance therefore affect nematode populations capable of posing risk to subsequent plantings of intolerant crops or varieties. Resistance must be studied in the greenhouse. Tolerance and resistance levels are unknown for PNW wheat and barley varieties. If fields are infested with *P. neglectus* and/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.

Crop management options other than genetic tolerance and resistance are not likely to be economically feasible for dryland wheat producers in low-rainfall regions. Chemicals are neither registered nor economically feasible in dryland agriculture. Tillage intensity does not greatly affect populations of root-lesion nematodes. 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; e.g., the green bridge must be totally eliminated. Crop rotations may be helpful, detrimental, or neutral. Minimal reproduction of these nematodes occurs on crops such as field pea and safflower, which can reduce the risk to subsequent crops. Reproduction rates may be high on many chickpea, amplifying the risk to subsequent intolerant wheat crops. Most canola, mustard and lentil varieties are very favorable for reproduction of *P. neglectus* and much less favorable for reproduction of *P. thornei*. Reproduction is generally greater on wheat than barley but large differences occur among varieties of these crops.

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. Plant biomass and grain yield for moderately tolerant varieties were often double those for intolerant varieties in low- to intermediate-rainfall regions between Moro and Pendleton, Oregon (2, 3). Increasing densities of root-lesion nematodes were strongly associated with reduced growth and yield of intolerant varieties. The relationship between nematode population and wheat yield was also evaluated by comparing yields in adjacent plots treated or not treated with the nematicide aldicarb (Temik 15G; which is not and will not be registered for this use). Application of Temik often led to a doubling of yield for intolerant varieties of spring wheat.

The first evaluations of PNW-adapted wheat and barley varieties and advanced breeding lines were performed during 2006. These experiments evaluated the influences of *P. neglectus* and *P. thornei* 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 current production on 95% of winter cereals acreage and 85% of spring cereals acreage in Oregon and Washington. Australian susceptible and tolerant "standards" were included for comparison in each experiment. Yields of intolerant entries on *P. neglectus*-infested soil were half those for tolerant entries, for both spring- and fall-planted cereals (Fig. 2). 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 (Fig. 3), indicating a need to screen wheat varieties separately against each *Pratylenchus* species. Refinements were found to be necessary for Temik application rates and timing in fall-planted nurseries. These adjustments (higher rates and split applications) are being studied during 2006-2007. Rigorous repetitive screening during at least three seasons is required to examine the stability of the preliminary data acquired during 2006. It is anticipated that testing proposed here will enable us to quantify PNW-adapted varieties for tolerance to each species of root-lesion nematode, and to screen exotic germplasm to identify sources that carry the greatest possible level of genetic tolerance and resistance.

Selecting and breeding wheat for tolerance and resistance is very likely to improve productivity and economic efficiency where-ever susceptible host plants dominate the cropping system, including each crop in the rotation and also the grass and broadleaf weeds. Overall productivity of crop rotations should also be able to be improved by using a resistant wheat or barley variety. Research proposed here, with respect to *P. neglectus* and *P. thornei* on PNW winter wheat varieties and advanced breeding lines, would quantify tolerance levels under field conditions. Parallel studies with spring wheat and barley have been proposed for funding by the STEEP program, and complementary genetic resistance studies will be performed as part of a USDA-ARS project.

References to research with root-lesion nematodes on wheat in the PNW:

1. Smiley, R.W., K. Merrifield, L.-M. Patterson, R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2004. Nematodes in dryland field crops in the semiarid Pacific Northwest United States. *Journal of Nematology* 36:54-68.
2. Smiley, R.W., R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2005. *Pratylenchus thornei* associated with reduced wheat yield in Oregon. *Journal of Nematology* 37:45-54.
3. Smiley, R.W., R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2005. Suppression of wheat growth and yield by *Pratylenchus neglectus* in the Pacific Northwest. *Plant Disease* 89:958-968.

C. Background/Scope:

- 1) Location of the problem or number of acres affected: Throughout the region; not restricted by precipitation zone, temperature, or soil type. Most prevalent in annual crop systems and in "functional annual crops" in which winter wheat-summer fallow rotations include volunteer cereals and winter-annual weeds during the "fallow" winter.
- 2) Classes and/or varieties affected: All classes of wheat.
- 3) Other work conducted on this same issue in the PNW and the US: Research proposed

here is not related to any current or previous projects funded by the PNW wheat industry (WWC, IWC, and OWC) or by STEEP. There is no comparable research in the USA. The PI receives funds from an OSU subcontract to the USDA-ARS (SCA #58-5348-9-100, "Control of Root Diseases of Wheat and Barley") to perform research on applied strategies to manage wheat and barley root diseases caused by *Fusarium* crown rot, root-lesion nematodes, and cereal cyst nematodes. The ARS grant is sufficient to fund about one-third of the tolerance and resistance research proposed here. It is proposed that leveraging funds for tolerance studies be sponsored by the wheat commissions (winter wheat) and STEEP (spring wheat and barley).

4) Preliminary studies showing research is feasible: Successive stages of this topic have been actively researched at OSU-Pendleton since 1999 (see "Goals"). Our earlier research protocols have each been endorsed through the peer review process during publication of technical journal papers. During 2006, one year of preliminary research at two locations supported the need to quantify levels of tolerance for PNW-adapted wheat varieties and lines. The most recent work was coordinated and performed by Mr. Jason Sheedy who, before being hired at Pendleton during 2005, had 12 years of experience working in a root-lesion nematode resistance breeding program in Australia. Mr. Sheedy's responsibility currently includes coordination of tolerance and resistance screenings for root-lesion nematodes, identification and introgression of higher levels of resistance and tolerance into locally adapted varieties, and identification of plant resources useful for developing molecular markers for research by collaborating state and federal wheat barley breeders.

5) Reason for addressing the problem now: Discovery studies conducted with Australian wheat varieties from 1999 to 2005 clearly demonstrated the breadth and extent of this problem in the PNW. In first-year studies with PNW-adapted germplasm, a wide range of reactions were noted for commercial varieties and it was particularly noted that some advanced breeding lines were among the least tolerant entries tested. It appears necessary to 1) quickly identify the level of risk associated with selecting a current variety for planting into nematode-infested land, 2) begin testing advanced breeding lines for tolerance and resistance to root-lesion nematodes, and 3) identify plant introductions with the highest levels of tolerance and/or resistance to improve the performance for the least tolerant varieties and breeding lines in the PNW.

D. Economics:

Tests in Oregon have shown that yields of intolerant varieties can sometimes be doubled by application of a non-registered nematicide, and that yields of moderately tolerant varieties can be nearly double the yields of intolerant varieties, even though varieties of both types have comparable yields on fields with low populations of root-lesion nematodes. Resistant varieties will surely improve yields in annual spring cropping systems and are likely to also improve yields in some winter wheat-summer fallow rotations. Valid economic projections for the overall wheat industry are not possible at this time.

Process:

A. Objective: Characterize levels of field tolerance to *Pratylenchus neglectus* and *P. thornei* in Pacific Northwest winter wheat varieties and advanced breeding lines.

B. Procedures: Genetic tolerance measures a plant's ability to yield acceptable well even when invaded by moderately high populations of root-lesion nematodes. The tolerance index is calculated from the ratio of grain yields in untreated and in nematicide-treated soil. Tolerance indices for *P. neglectus* and *P. thornei* will be determined for the selection of

winter wheat entries examined during 2005-2006 (Fig. 2). These entries include 36 commercial and advanced breeding lines supplied by Drs. Jim Peterson (OSU), Kim Campbell (USDA-ARS), and Steve Jones (WSU). The commercial varieties are currently produced on about 95% of fall-planted in Oregon and Washington. Tests will also include four Australian "standards" with known tolerance levels to each *Pratylenchus* species. The use of Australian standards will be discontinued once we have sufficient data to select "local standards" from among PNW cultivars and/or lines tested. This switch to local standards should be possible after only two or three years of testing.

A survey during 2005 identified fields with high populations of *P. neglectus* or *P. thornei*, with minimal mixture among species. *P. neglectus*-infested fields are on the Bill Jepsen Farm near Heppner. *P. thornei*-infested fields are at the Agricultural Research Center near Pendleton. Fields at both locations are managed without tillage. The Jepsen fields have a history of annual direct-drill spring crops including barley, wheat and mustard. The Pendleton fields are in a three year-rotation of spring barley, winter wheat, and chem-fallow. Tests may follow any of the crops at the Jepsen farm and the chem-fallow at Pendleton. Grid sampling to 4-foot depth or restrictive layer will be performed in prospective fields during May or June 2007 to identify test sites with high and uniform populations of nematodes.

During September 2007 the test sites will be measured and staked, sprayed with glyphosate if necessary to kill volunteer cereals and grass weeds, and fertilized at rates based on soil testing and anticipated yield potential. Fertilizer will be applied using an 8-foot wide Fabro drill with double-disk openers at 10-inch spacing. In September or October 2007, the wheat entries will be planted without tillage using a John Deere HZ drill with openers at 14-inch spacing, a cone seeder for dispensing seed, and a Gandy box and drop tubes for dispensing Temik below the seed. Forty wheat entries will be planted using a split-plot design with 6 x 30-foot plots replicated 3 times. Temik-treated and control plots for each entry will be planted in adjacent drill strips, allowing side-by-side comparison of treatments for each entry. Each experiment will consist of 240 plots; 40 entries x 3 replicates x 2 chemicals (none or Temik).

Seedling emergence and plant growth will be evaluated as necessary on each experimental area. A broadleaf weed spray will be applied during spring. Plots will be harvested using a small plot combine and grain yield and test weight will be calculated. The root-lesion nematode tolerance index for each entry will be calculated as the ratio of grain yield in control and Temik-treated plots. Data will be analyzed using ANOVA or REML statistical procedures. Results will be compared to preliminary data collected during 2006 and 2007.

Australian research has shown that once tolerance indices are established for each wheat variety or line, there is usually a significant correlation between that index and grain yield in control plots. Preliminary data suggests that this relationship also occurs for spring-planted cereals in Oregon (Fig. 4) but that additional refinements in technique are necessary for fall-planted cereals. The latter appears to be an easily corrected artifact of our Temik application procedure. Temik effectively retards nematode reproduction for only about six weeks, and that time interval represents a much greater proportion of the growth cycle for spring- than fall-planted cereals. It is anticipated that higher application rates at the time of planting, and/or split applications in fall and spring, will improve the "statistical fit" for correlating the tolerance index to yield of fall-planted cereals. That relationship is being evaluated with a sub-set of five varieties during 2007. If confirmed in the test during 2007 and in the main experiment during 2008 (this grant for FY2007), then additional tests during 2009 and 2010 will not require the use of Temik. Eliminating Temik would greatly increase the screening

efficiency and safety because more entries, larger plot size, or more replicates could be tested, and the necessity to destroy grain produced on Temik-treated land would be eliminated.

Determining tolerance based on untreated grain yield alone measures the combination of genetic yield potential and tolerance to root-lesion nematode. This is commonly referred to as 'practical tolerance' and is the yardstick used in most breeding programs actively engaged in breeding for tolerance to root-lesion nematodes overseas. Tolerance testing is required over three consecutive seasons to establish multi-year data for each entry. Since this closely matches the testing requirement for releasing elite breeding lines in the PNW, it appears possible that subsequent screening for root-lesion nematode tolerance could be combined with each state's cereal testing nursery program. For instance, each of the state nurseries could be expanded to be produced at the two well-studied test sites in Oregon. Alternatively or additionally, soil profiles in each of the 30 to 40 variety test sites in Idaho, Oregon and Washington could be evaluated for populations and identities of root-lesion nematodes to determine if an existing trial site already serves this need. In any case, characterizations of existing test sites may help to interpret variability in yield rankings among varieties in each trial.

The STEEP research program has been asked to fund parallel studies with spring wheat and spring barley. If funded, those tests will be performed at the same locations described for the winter wheat studies proposed here. Methods will be similar. Entries for the tests were provided by Drs. Jim Peterson and Patrick Hayes (OSU), Kim Campbell (USDA-ARS), Kim Kidwell, Steve Jones, and Steve Ullrich (WSU), and Alan Dyer (Montana St. Univ.). The commercial varieties are currently produced on more than 85% of spring-planted wheat and barley acres in Oregon and Washington.

Complementary studies on genetic resistance will be funded by the OSU sub-contract to the USDA-ARS. The goal is to develop *P. neglectus* and *P. thornei* resistance ratings for Pacific Northwest varieties and breeding lines, and for promising germplasm from other breeding programs. Genetic resistance is a measure of the nematode's reproductive rate, calculated as the ratio of initial (P_i) and final (P_f) numbers of nematodes in roots plus soil, as determined during a bioassay performed under controlled conditions. The bioassay uses nematode-free soil that is inoculated with known numbers of nematodes derived from pure cultures of the appropriate species. Plants that support reproduction ($P_f > P_i$) are considered susceptible and plants that allow little or no reproduction ($P_i \geq P_f$) are considered resistant. It is therefore important to integrate both tolerance and resistance into wheat cropping systems where root-lesions are known to cause yield reduction.

The resistance experiments are briefly described because they are a critical component of the overall program. Pure cultures of *P. neglectus* and *P. thornei* are reared in incubators and in the greenhouse. These cultures provide the millions of well-identified and uniform nematodes required for resistance screening experiments. Wheat collections have been acquired from CIMMYT's Root Disease Testing Nursery program, Australia (lines with known reactions), Kansas State University (Iranian landraces and addition/deletion lines derived from wild relatives of wheat), and elsewhere. During the winter of 2007-2008, seed of about 330 entries will be grown in 2,000 greenhouse pots, each of which will contain an initial population of 1,000 nematodes (P_i). Sixteen weeks after planting, pots will be harvested and the soil and roots processed to determine the final population of nematodes (P_f). The P_f/P_i ratio will be analyzed and tests will be repeated during 2008-2009. Data from two years of testing will result in a ranked listing of *P. neglectus* and *P. thornei* resistances for Pacific Northwest varieties and breeding lines, and for promising germplasm from other breeding programs.

C. Cooperation and Coordination: Plant materials for this research have been and will continue to be supplied by wheat and barley breeders throughout the Pacific Northwest and by the CIMMYT plant pathologist who coordinates the CIMMYT/ICARDA Root Disease Testing Nursery program (see the list of cooperators for this grant). Base-level funding is provided by a USDA-ARS research program that includes sub-contracts to the University of Idaho (Dr. Juliet Windes, Idaho Falls) and Washington State University (Dr. Scot Hulbert; previously, Dr. Jim Cook), in addition to Oregon State University (PI for this proposal). The USDA funding also provides support for scientists in the parent USDA-ARS program, including Drs. David Weller, Tim Paulitz, Linda Thomashow, and Patricia Okubara. The principal investigator of this proposal has a strong track record for publishing research papers that include appropriate levels of recognition to those who provide germplasm and other technical materials and/or guidance, as exemplified by co-authoring recent technical manuscripts with Drs. Kidwell, Cook, and Paulitz, and co-authoring recent extension bulletins with Drs. Cook and Paulitz.

D. Review:

The principal investigator participates in 15 to 25 public presentations annually, nearly equally divided among venues in Oregon and Washington. Speeches, written proceedings, and/or posters are presented at experiment station field tours, county extension service crop tours and training schools, monthly or annual meetings of agricultural consultants, training schools or farmer meetings coordinated by agricultural chemical companies, professional conferences, industry conferences such as PNW Direct-Drill, guest lectures and seminars at universities, and research reviews by funding agencies such as STEEP and OWC. If partially funded by the WWC and/or IWC the PI would anticipate an expectation to participate in appropriate research reviews and periodic reports for those agencies, either directly or through the OWC.

E. Locations:

Plant tolerance and resistance are plant characteristics that are equally expressed across environments. To maintain continuity of cost-effective research, the proposed genetic tolerance experiments will occur initially at two locations where appropriately high and well-defined populations of the two nematode species are already defined. *P. neglectus* will be studied at a commercial farm between Heppner and Condon, Oregon (12-inch rainfall, 2,550-ft elevation). *P. thornei* will be studied at the Columbia Basin Agricultural Research Center near Pendleton (16-inch rainfall, 1,470-ft elevation). Resistance testing will be performed in the greenhouse and nematology laboratory at Pendleton.

Outcome

A. Expected Results: Productivity of winter wheat on fields infested with high populations of root-lesion nematodes should be improved. Results of this research will be communicated to producers, breeders and extension agents by 1) participating in industry and professional meetings (direct-drill, state grains organizations, county crops tours and winter meetings, experiment station field days, and professional meetings of pathologists, nematologists, and crop scientists), 2) suggesting that listings be published in seed-buyers guides, 3) writing experiment station publications and wheat-industry magazine articles, 4) writing one PNW extension bulletin, and 5) publishing at one or more technical journal manuscripts. Demonstration plots will be shown and/or discussed during field tours. Although not part of this project, on-going testing would then become focused on elite breeding lines during the three years prior to their release. Genotypes with superior resistance ratings will be evaluated for agronomic characteristics in the field to select the best possible parents for crossing with PNW-adapted varieties. Studies proposed for funding by the wheat industry

will be complemented by USDA-ARS funding for laboratory research to 1) confirm local applicability of an Australian-developed molecular marker for detecting a gene for resistance to *P. thornei*, 2) develop complementary markers to detect other resistance genes for *P. thornei*, 3) develop markers for resistance to *P. neglectus*, and 4) refine molecular diagnostic tests capable of differentiating *P. neglectus* and *P. thornei* in field soils. The ARS-funded research will be fully integrated into this wheat industry-funded research.

B. Payback Timeline: Assignment of tolerance indices for winter wheat is anticipated within three months after this experiment is terminated in June 2010. Identification of genotypes with superior resistance is likely during 2009 and PNW-adapted germplasm containing genes for resistance to each nematode species will be available for use by wheat breeders by the end of this three-year project.

C. Progress: When the proposed wheat industry-funded research is initiated the first and second preliminary seasons of field tolerance testing will have been completed. Further minor refinements are likely to occur throughout the duration of these tolerance testing experiments. Likewise, the first season of resistance testing in the greenhouse will also have been completed but will need to be subjected to repetitions to assure the validity of results. Initial crosses have already been made between PNW-adapted spring and winter wheat varieties or breeding lines and introduced genotypes with moderate to high levels of resistance and/or tolerance to one or both nematode species. Additional crosses are planned and the F1 populations from the initial crosses will be backcrossed once with the PNW-adapted parents before this project begins.

D. Impact: Smiley et al. published results showing that yields of intolerant spring and winter wheat varieties had yields as low as half those for tolerant varieties. It is unlikely that any of these varieties carried genes for resistance because populations of nematodes were high in the roots at the end of each experiment, increasing the risk to subsequent intolerant crop species. Accurate economic estimates have not been attempted but the value of this research will surely increase with further adoption of conservation farming practices such as chem-fallow and annual cropping.

E. Communication: Please refer to the "Process: Review" section for expectations at this stage of the proposal for funding.

Figure 1. 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 at Pilot Rock, Oregon. [reprinted from: Smiley, R.W. et al., 2004. Nematodes in dryland field crops in the semiarid Pacific Northwest United States. *Journal of Nematology* 36:54-68]

Figure 2. Preliminary data from the first year of screening spring- and fall-planted cereals on soil infested with moderately high populations of *Pratylenchus neglectus* at a farm near Heppner, Oregon, 2006; 39 spring wheat, 6 spring barley, 36 winter wheat, 5 winter barley, and 4 (or 5) Australian spring wheat "standards".

Figure 3. Preliminary comparison of the tolerance index (TI) for 80 wheat entries growing in soils infested with either *P. neglectus* or *P. thornei* during 2006, showing the need to perform independent screenings for each nematode species.

Figure 4. Comparison of tolerance index and grain yield for 79 wheat entries growing in soils

infested with *P. neglectus* during 2006, showing a statistically significant correlation for spring wheat but not for winter wheat. Grain yields are from control plots (not treated with Temik).