DISCOVERY AND DISTRIBUTION OF ROOT LESION NEMATODE, *PRATYLENCHUS NEGLECTUS*, IN MONTANA

by

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APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

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Wendy Ann Johnson

November 2007

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ABSTRACT

Root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) cause significant yield losses for wheat worldwide. To assess the prevalence of root lesion nematodes in Montana, soil samples were collected statewide in 2006 and 2007. In 2006, *P. neglectus* was found in 12 of the 17 counties and in 41% of all field samples surveyed. In 2007, *P. neglectus* was found in 11 of 15 counties and in 37% of all field samples surveyed. No *P. thornei* was found. For fields having root lesion nematode in 2006, *P. neglectus* mean population densities were 1213 nematodes/kg soil with population densities exceeding the damage threshold of 2500 nematodes/kg soil in 14% of the sampled fields. For fields having root lesion nematodes in 2007, *P. neglectus* mean population densities were 1303 nematodes/kg dry soil with densities exceeding the damage threshold of 2500 nematodes/kg dry soil in 13% of the samples. Damaging populations were restricted to the north central part of the state and were generally found in fields following a crop of winter wheat (p= 0.02). Stunt nematodes (*Tylenchorynchus* spp.) were detected in 93% and 85% of sampled fields for 2006 and 2007, respectively. New sources of tolerance and resistance to root lesion nematode are highly sought after due to limited breeding materials. Resistances of 16 cultivars were evaluated through inoculated greenhouse trials where multiplication of the pathogen was observed after 12 weeks of growth. No significant differences in multiplication factors (Rf= population final/population initial) were observed for the first trial (F test, $p=0.11$) though significant differences were evident between cultivars in the second trial (F test, $p<0.001$). From the greenhouse trials, the historic cultivar, Ceres was identified as a potentially useful source of nematode resistance. Tolerance evaluations were conducted at two nematode-infested sites (Ulm and Bozeman, MT) where the yield responses of 20 cultivars, with and without nematicide (Temik 15G ™) treatment, were compared. On average, nematicide treatments reduced yields at both sites (Ulm = 0.4% and Bozeman = 7.3%). No significant differences in nematode tolerances was detected among cultivars (Ulm, p=0.08; Bozeman, $p=0.14$).

CHAPTER 1

INTRODUCTION

Root lesion nematodes, belonging to the genus *Pratylenchus*, are the third most agriculturally important group of nematodes in the United States, following cyst nematodes (*Heterodera* and *Globodera*) and root knot nematodes (*Meloidogyne*) (Davis and MacGuidwin 2000). *Pratylenchus* spp. are endoparasites of a wide range of crops in temperate regions (Williams 2002). Their ability to multiply within host tissue allows root lesion nematodes to thrive in semi-arid wheat growing regions where the absence of free moisture limits free-living nematodes (Vanstone 1998).

The two species of root lesion nematodes associated with wheat production, *Pratylenchus thornei* Sher & Allen and *Pratylenchus neglectus* (Rensch) Filipjev, Schuurmans, and Stekhoven, have been documented as reducing wheat yields in Australia, Israel, Canada, Mexico, and the United States (Mojtahedi and Santo 1992; Orion et al. 1984; Taylor et al. 1999; Van Gundy et al. 1974; Vanstone et al. 1998; Yu 1997). In the United States, recent wheat losses associated with root lesion nematode have been reported in Utah, Oregon, and Washington (Smiley 2005b, 2005c; Thorne, 1961).

Wheat roots infested with root lesion nematodes display sloughing of cortical and epidermal cells, degradation of lateral roots, and loss of root hairs (Vanstone et. al. 1998). Overall, affected plants appear stunted with premature yellowing of older leaves, reduced tillering, and lower kernel weights (Smiley 2004). These symptoms are often confused with nutrient deficiencies (Taylor et al. 1999) or associated with root rot fungi (Taheri et al. 1994).

Cultural controls for root lesion nematode are limited. For research studies, the nematicide aldicarb (Temik 15G) has been shown effective in early protection of root development, but due to its persistence, toxicity, and cost is not used in commercial cereal production (Kimpinski et al. 1987). Studies show rotations with non-host alternative crops safflower, triticale, flax, and field pea help reduce populations of root lesion nematode (Smiley 2005a). For wheat growing regions of Oregon and Washington, economic damage thresholds for *P. neglectus* are reported at 2500 nematodes/kg dry soil and for *P. thornei* at 2000 nematodes/kg dry soil (Smiley et al. 2005b). Similar thresholds have been determined for Australia (Vanstone et al. 1998). Greater populations of *Pratylenchus* have been reported under annual wheat cropping systems as opposed to wheat fallow rotations (Smiley et al. 2004). The intensity of annually cropped wheat increases pathogen pressures, including those from plant pathogenic nematodes (Paulitz et al. 2002; Smiley et al. 2004).

Developing resistant wheat cultivars is an important part of most control strategies. Nematode resistance limits reproduction inside host tissues (Taylor et al. 2000). For root lesion nematodes, resistance is species specific (resistance genes that work for one species will not work for the other). For *P. neglectus,* the resistance gene, *Rlnn1* found in the moderately resistant Australian variety, ‘Excalibur’, has proven useful (Williams et al. 2002). Resistance to *P. thornei* was found in a single plant selection, GS50a, discovered in an Australian field of the susceptible variety, ‘Gatcher’ (Zwart et al. 2004). Wheat may also display tolerance, which is defined as the host’s ability to overcome damaging effects of feeding. Tolerance is independent from resistance (Trudgill 1991) and is usually identified through paired plot trials using the nematicide, Temik (Taylor 1997; Thompson and Clewett 1989; Vanstone et al. 1995; and Vanstone 1998). Tolerance and resistance are shown to be independent phenotypic characters and a superior cultivar would be one that displayed both tolerance and resistance to root lesion nematodes.

Stunt nematodes, *Tylenchorhynchus* Cobb, have been far less studied than root lesion nematode. Yield reductions have been linked to stunt nematodes, but damage thresholds are hard to assess due to difficulty identifying stunt nematode species and confounding factors such as soil moisture (Smiley et al. 2005a). In spite of their wide host range and general abundance, little field data has been collected on losses due to stunt nematode. In greenhouse studies, damage thresholds for stunt nematodes as low as 1000 nematodes/kg of soil were reported (Thakar et al. 1986). Stunt nematode symptoms are similar to those of root lesion nematode and include stunting, yellowing of older leaves, reduced tillers and kernel weight (Thakar et al. 1986).

Montana has 2.8 million hectacres of low rainfall, annually cropped wheat acreage, acreage with conditions similar to those reported in Utah, Idaho, Oregon and Washington (Hafez 1992; Nicol 1999; Smiley 2005b). Since Montana has conditions favorable for root lesion nematode, and since knowledge of the nematode species involved is important to future breeding efforts, this project was undertaken. The objectives of this project were to 1) determine the species and distribution of root lesion nematodes among Montana’s wheat acreage, and 2) determine their potential impact on wheat production. In the process, this project assessed the stunt nematode populations throughout the state. A preliminary report has been made for this research (Johnson et al. 2007).

CHAPTER 2

ASSESSMENT OF ROOT LESION NEMATODE SPECIES AND DISTRIBUTION IN MONTANA

Introduction

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Materials and Methods

Seventeen Montana counties were chosen for the survey based on wheat acreage (NASS 2004) with those selected accounting for 82 % of total wheat acreage for the state. All soil samples for the survey were taken after spring planting from April through late June in 2006 and 2007. In 2006, a total of 148 bulked soil samples were collected for processing. Eleven counties sampled 10 fields, 1 county sampled 8 fields, 1 county sampled 7 fields, 3 counties sampled 6 fields, and 1 county sampled 5 fields. In 2007, 116 bulked soil samples were collected for processing. One county sampled 11 fields, 7 counties sampled 10 fields, 1 county sampled 8 fields, 1 county sampled 7 fields, 1 county sampled 6 fields, 2 county sampled 5 fields, and 2 counties sampled 2 fields.

For each field sampled, county agents took nine soil cores in a “W” pattern. The cores were collected starting 30 m from the edge of the field with 25 ft. separating each core from its neighbor. Cores were taken to a 23 cm depth using a standard 30 cm soil probe. The 9 soil cores were then combined and mixed thoroughly to make a bulked soil sample. The bulked samples were then placed in a soil collection bag labeled with the following information: grower, county, previous crop, and cropping systems: no-till versus conventional tillage and annual crop versus summer fallow.

Once soil samples were received, they were placed in cold storage at 4°C until processing. The Whitehead tray method was modified to extract nematodes from the soil samples (Whitehead and Hemming 1965). For each soil sample, nematodes were extracted from 200 g of fresh soil over 48hrs at 20°C using 2 L of tap water. After the 48hr period, the extraction water was passed through a 20 μm mesh sieve. The nematodes were stored in water at 4°C until microscopic examination could be conducted. Extracted nematode populations were examined for the presence of both root lesion nematodes (*P. neglectus* and *P. thornei*) and stunt nematodes (*Tylenchorhynchus* spp.). Concurrent with nematode extractions, percent soil moisture was determined by drying 100 g of fresh soil at 70°C for 48 hrs. Time from receiving to processing samples varied from one day to two weeks.

To examine nematode numbers, 2 ml of the nematode suspension was placed into a McMaster Counting Slide (Chalex Corporation, Wallowa, OR) and the nematodes were counted under 10X magnification on Nikon's Eclipse 50i microscope (Kent, WA). Resulting nematode counts were translated into adult nematodes/kg of dry soil. Nematode identifications were conducted based on length, width, and vulva position in relation to percent body length. *Pratylenchus neglectus* is distinguishable from *P. thornei* by being notably shorter, wider, and having a more pointed tail than the dorsally flattened tail of *P. thornei* (Handoo 1989). *Tylenchorhychus* spp. were identified to genus by having a strong stylet, non-overlapping esophagus, didelphic vulva position, and conical tail shape (Mai and Mullin 1960). Twelve representative samples were sent to Oregon State University nematode diagnostic laboratory and ten samples sent to Columbia Basin Agricultural Research Station (Pendleton, OR) for confirmation of results. Pair-wise comparisons were made for fields where nematodes were detected based on information reported, including previous year crop, wheat fallow versus annual cropping systems, and conventional versus no-till field management.

Results

In 2006, *Pratylenchus neglectus* was detected in 62 of 148 samples examined, involving 12 of the 17 surveyed counties. *P. neglectus* populations were prominent in north-central Montana. Fergus, Chouteau, and Cascade counties of this area had mean populations of $\bar{x}$ = 3375 *P. neglectus/*kg soil, $\bar{x}$ = 3844 *P. neglectus*/kg soil, and $\bar{x}$ = 3252 *P. neglectus*/kg soil, respectively (Table 1). *Pratylenchus* spp. were not found in fields of the northwestern most portion of the state, including counties: Daniels, Sheridan, Richland, and Dawson (Figure 1A).

Figure 1A

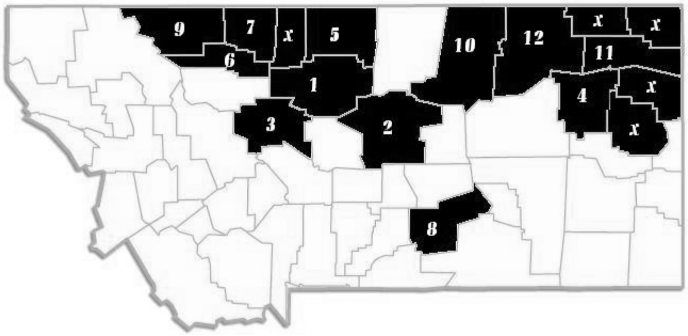
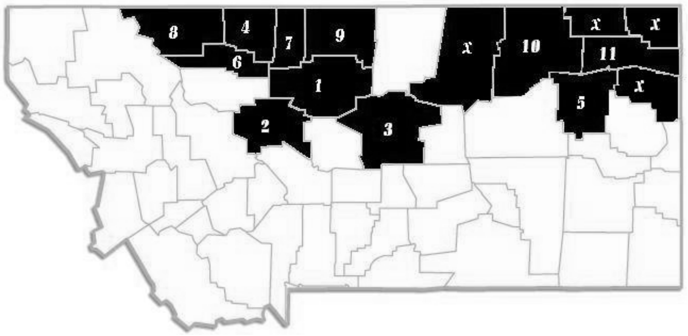


Figure 1B



Figures 1A and 1B. Counties surveyed in 2006 (1A) and 2007 (1B) for root lesion nematode (*P. neglectus*). Counties are ranked based on average RLN populations. *x* represents counties sampled where no RLN was found.

Table 1. Incidence and average populations of root lesion and stunt nematodes for 17 counties sampled in Montana for 2006. [a]Root lesion nematode incidence as a percentage of samples examined from each county. [b]Root lesion nematode incidence above damage threshold is the percentage of examined samples that exceeded 2500 *P. nelgectus*/ kg soil.

County	$\bar{x}$ RLN	RLN[a] Incidence	RLN[b] Incidence above damage threshold	$\bar{x}$ Stunt	Stunt Incidence
Chouteau	3844	60%	30%	1036	90%
Fergus	3375	100%	70%	2310	100%
Cascade	3252	80%	40%	667	90%
McCone	1440	70%	20%	2485	100%
Hill	880	60%	10%	3005	100%
Pondera	679	40%	10%	1410	100%
Toole	565	40%	10%	1860	100%
Yellowstone	301	90%	0%	2311	100%
Glacier	89	20%	0%	2544	90%
Phillips	73	50%	0%	420	90%
Roosevelt	61	10%	0%	1672	100%
Valley	5	10%	0%	1460	90%
Liberty	0	0%	0%	2970	100%
Dawson	0	0%	0%	1900	100%
Sheridan	0	0%	0%	202	28%
Richland	0	0%	0%	303	100%
Daniels	0	0%	0%	1895	100%

Table 2. Incidence and average populations of root lesion and stunt nematodes for 15 counties sampled in Montana for 2007. [a]Root lesion nematode incidence as a percentage of samples examined from each county. [b]Root lesion nematode incidence above damage threshold is the percentage of examined samples that exceeded 2500 *P. nelgectus*/ kg soil.

County	$\bar{x}$ RLN	RLN[a] Incidence	RLN[b] Incidence above damage threshold	$\bar{x}$ Stunt	Stunt Incidence
Chouteau	3306	80%	40%	5895	90%
Fergus	2400	90%	20%	756	90%
Cascade	2670	100%	50%	1220	50%
Toole	2375	20%	10%	1001	80%
McCone	1285	50%	10%	1330	100%
Hill	953	50%	10%	1330	100%
Pondera	811	45%	18%	725	45%
Liberty	385	20%	10%	4254	100%
Glacier	100	30%	20%	1825	90%
Roosevelt	24	10%	0%	1306	87%
Valley	29	50%	0%	1337	100%
Phillips	0	0%	0%	538	83%
Sheridan	0	0%	0%	751	85%
Daniels	0	0%	0%	1020	60%

In 2007, *Pratylenchus neglectus* was detected in 43 of 116 samples examined, including 11 of 15 surveyed counties. The largest populations were predominantly in the north central counties of Fergus, Chouteau, and Cascade, having mean populations $\bar{x}$ = 2400 *P. neglectus*/kg dry soil, $\bar{x}$ = 3306 *P. neglectus* /kg dry soil, and $\bar{x}$ = 3205 *P. neglectus* /kg dry soil, respectively (Table 2). *Pratylenchus* was not found in Phillips during 2007, although it was found there in 2006. Samples from the Northwestern most portion of the state yielded no *Pratylenchus* spp. (Figure 1B).

For 2006, analysis of samples with *P. neglectus* populations showed that fields having previously been planted to winter wheat had significantly higher mean populations ($\bar{x}$ = 3390 *P. neglectus*/kg dry soil, respectively) than fields having previous spring wheat crops ($\bar{x}$ = 1275 *P. neglectus*/kg dry soil, respectively (p= 0.02) (Figure 2A). There were no differences in mean populations between no-tilled and conventional tilled production fields ($\bar{x}$ = 2886 *P. neglectus*/kg dry soil, and $\bar{x}$ = 1672 *P. neglectus*/kg dry soil, respectively (p=0.14)). Nematode populations in annually cropped fields were not significantly different from wheat fallowed fields ($\bar{x}$ = 2800 *P. neglectus*/kg dry soil, and $\bar{x}$ = 2134 *P. neglectus*/kg dry soil, respectively (p=0.51)).

Figure 2A

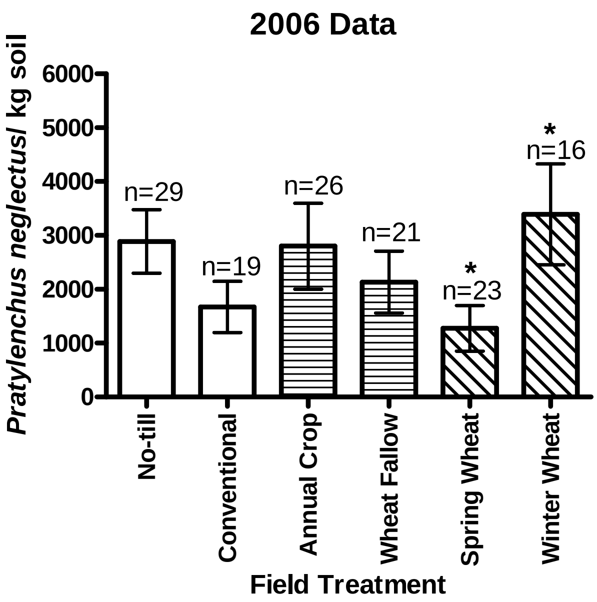
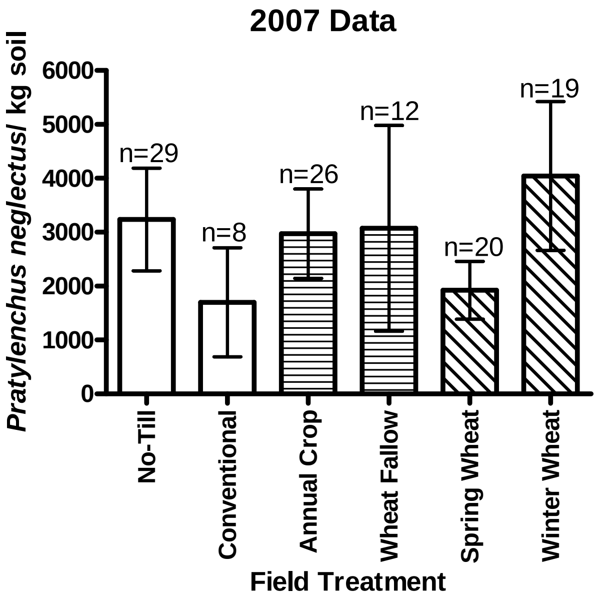


Figure 2B



Figures 2A and 2B. Comparison of fields containing root lesion nematode (*P. neglectus*) populations in 2006 (2A) and 2007 (2B) showing no-till versus conventional, annual crop versus wheat fallow, and spring wheat versus winter wheat. Line bars represent standard error. * Represents a significant difference (*p*= 0.02).

In 2007, analysis of samples with *P. neglectus* revealed that fields having a previous crop of winter wheat had higher populations than fields previously planted with spring wheat, but the data was not significant ($\bar{x}$ = 4045 *P. neglectus*/kg dry soil, and $\bar{x}$ = 1921 *P. neglectus*/kg dry soil, respectively (p=0.15)(Figure 2B). There was no significant difference in means between no-till and conventional till production fields ($\bar{x}$ = 3235 *P. neglectus*/kg dry soil, and $\bar{x}$ = 1699 *P. neglectus*/kg dry soil, respectively (p= 0.42)). Mean populations were not different between annually cropped fields and wheat fallowed fields ($\bar{x}$ = 2974 *P. neglectus*/kg dry soil, and $\bar{x}$ = 3072 *P. neglectus*/kg dry soil, respectively (p=0.95)).

For 2006, stunt nematodes (*Tylenchorhynchus* spp.) were recovered from 93% of all samples examined and in all counties surveyed. For fields containing *Tylenchorhynchus*, the mean population was $\bar{x}$ = 1674 *Tylenchorhynchus*/kg dry soil. Populations were higher in annually cropped fields than fallow fields ($\bar{x}$ = 2082 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 1357 *Tylenchorhynchus*/kg dry soil, respectively (p= 0.01)(Figure 3A). Although not significant, stunt nematode populations were higher in no-till systems than in conventional systems, ($\bar{x}$ = 1920 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 1504 *Tylenchorhynchus*/kg dry soil, respectively) and in fields with previous spring wheat crops than fields with previous winter wheat crops ($\bar{x}$ = 1778 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 1348 *Tylenchorhynchus*/kg dry soil, respectively).

Figure 3A

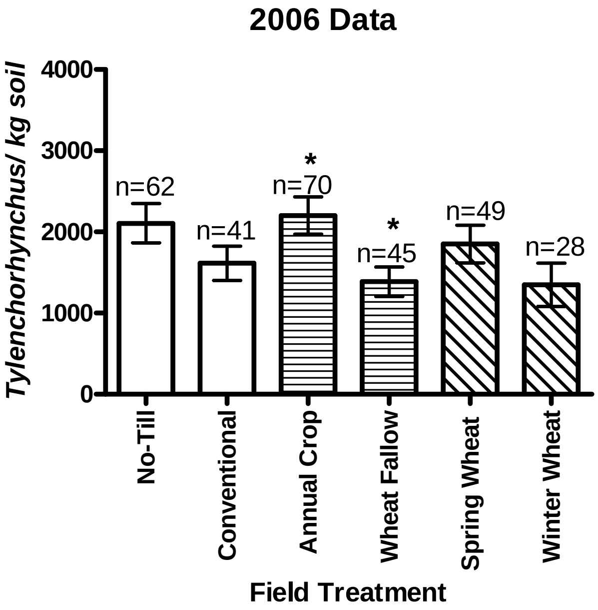
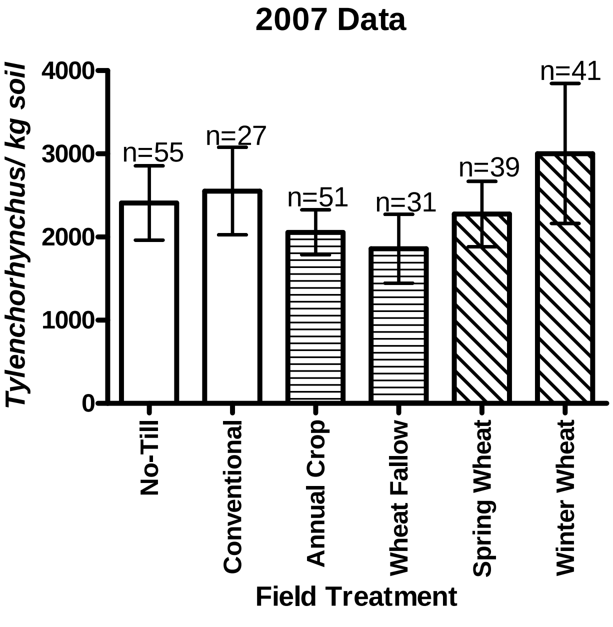


Figure 3B



Figures 3A and 3B. Comparison of stunt nematode populations for 2006 (3A) and 2007 (3B) in no-till versus conventional, annual crop versus wheat fallow, and spring wheat versus winter wheat. Line bars represent standard error.
* Represents a significant difference (*p*= 0.01).

For 2007, stunt nematode populations were present in 85% of all samples examined and in all counties involved. For fields containing *Tylenchorhynchus*, the mean population was 2358 *Tylenchorhynchus*/kg dry soil. Population means were similar in annually cropped fields and in fallow fields ($\bar{x}$ = 2054 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 1858 *Tylenchorhynchus*/kg dry soil, respectively (p=0.67)(Figure 3B). Populations were slightly lower in no-till systems than in conventional systems ($\bar{x}$ = 2409 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 2551 *Tylenchorhynchus*/kg dry soil, respectively). In fields with previous spring wheat crops the population means were higher but not significantly different than fields with previous winter wheat crops ($\bar{x}$ = 2276 *Tylenchorhynchus*/kg dry soil, and $\bar{x}$ = 3002 *Tylenchorhynchus*/kg dry soil, respectively).

Among the fields sampled in 2006, 60 were resampled in the 2007 survey. From these 60 fields, 41 fields had root lesion nematode detected in either one or both years. Regression analysis for the 41 resampled fields showed no correlation between the first years population and the next (R^2= 0.03, p=0.25). Of the resampled fields, 68% detected nematode populations in only one of the two years.

Pratylenchus thornei was not detected in any of the samples examined. An additional unknown species of root lesion nematode was detected but was sparse in numbers and so it was ignored for this project.

Discussion

This is the first report of *Pratylenchus neglectus* in the state of Montana. For other wheat growing regions, damage thresholds for *P. neglectus* are reported at 2500 nematodes/kg of soil (Smiley et al. 2005b; Vanstone et al. 1998). Field sites in Montana where *P. neglectus* populations have exceeded this damage threshold are primarily in north central Montana and primarily in winter wheat. Since 14% of fields sampled in 2006 and 13% of fields sampled in 2007 detected populations over the damage threshold, estimated impact acreage for Montana would amount to 148,000 hectares. In the northeast corner of Montana where low or no populations of root lesion nematode were detected, winter wheat is either not typically grown or grown in rotation with safflower, flax, and field peas, crops that are not host to *P. neglectus* (Smiley 2005b).

Finding higher populations of *P. neglectus* in fields following a winter wheat crop than a spring wheat crop in 2006 was unexpected since there have been fewer reports of injury in winter wheat than spring wheat (Mojahedi and Santo 1992). Studies in Oregon show spring wheat yield losses of 36% correlating to *P. neglectus* populations (Smiley 2005c). Relationships between spring nematode populations and yield losses have been confirmed for both spring and winter wheat in preliminary studies conducted in Montana (data not shown). Higher nematode populations in winter wheat are probably due to a longer growing season and overall cooler soil temperatures, optimal for *P. neglectus* reproduction.

No *Pratylenchus thornei* was found in any of the examined samples. The distribution of *P. thornei* in North America extends from the state of California: north to Washington state, east to Colorado state, and farther northeast into southern Ontario (Yu 1997). The absence of *P. thornei* might be interpreted that it simply has not been introduced into Montana at this time. Until now, *P. neglectus* and *P. thornei* had not been reported in Montana. Lack of *P. thornei* might be due to previous absence of the nematodes from Montana or limiting attributes of Montana’s environment keeping this particular species out. Soil texture is considered a limiting factor for *P. thornei* colonization. However, examination of soil types for the majority of sampled sites consisted of silty clay loam or clay loam (data not shown) (USDA 2007), preferred soil types for *P. thornei* (Thompson 2000; Vanstone and Nicol 1993).

In 2007, a resampling of 60 fields showed no correlation between samples taken in consecutive years. This indicates that sampling results for individual fields across years are independent. There are several factors that may explain this. Fields in Montana typically exceed 200 hectares. Data from this study suggest sampling protocols used for this study are inadequate for measuring entire field populations and that returning to fields without specific locations provide considerable variation. An additional explanation is that field populations of the nematode show considerable fluctuations over time and previous field history was a factor in sampled populations.

Stunt nematode populations were consistent during both years. These results are similar to a recent survey of plant parasitic nematodes that concluded factors such as tillage, crop type, and watering had no effect on stunt nematode populations (Strausbaugh 2004). For fields not containing root lesion nematodes, the high incidence of *Tylenchorhynchus* amongst soil samples acted as a positive control indicating soil samples were properly handled. The high levels and wide distribution of stunt nematode suggest these nematodes may be an additional concern for Montana’s wheat producers.

This study has established the predominant species of root lesion nematode, *Pratylenchus neglectus,* is present in the state of Montana and is of concern to growers. Screening for tolerant and resistant varieties of winter and spring wheat to *Pratylenchus neglectus* is underway, along with, establishing predictive values for yield losses in important Montana small grain varieties. Due to a lack of other controls for root lesion nematode, resistant lines will become an essential component for grower management practices. There is little estimation as to why *P. thornei* did not occur in the study and requires further survey effort in surrounding regions to determine if introduction of the pest is avoidable. Occurrence of stunt nematode was extensive, but its importance is not well understood. Given its prevalence, its interaction and pathogenicity with wheat as a pest should be further investigated.

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CHAPTER 3

EVALUATION OF MONTANA SPRING WHEAT CULTIVARS FOR RESISTANCE AND TOLERANCE TO THE ROOT LESION NEMATODE, *PRATYLENCHUS NEGLECTUS*

Introduction

Root lesion nematodes, *Pratylenchus* spp., attack a wide range of crops in temperate regions (Williams 2002). The two species of root lesion nematodes associated with wheat production, *Pratylenchus thornei* Sher & Allen and *Pratylenchus neglectus* (Rensch) Filipjev, Schuurmans, and Stekhoven, have been documented as reducing wheat yields in Australia, Israel, Canada, Mexico, and the United States (Mojtahedi and Santo 1992; Orion et al. 1984; Taylor et al. 1999; Van Gundy et al. 1974; Vanstone et al. 1998; Yu 1997). In the United States, recent wheat losses associated with root lesion nematode have been reported in Utah, Oregon, and Washington (Smiley 2005b, 2005c; Thorne 1961).

As endoparasites, root lesion nematodes have the ability to multiply within host tissue allowing them to thrive in semi-arid wheat growing regions where the absence of free moisture limits free-living nematodes (Vanstone et al. 1998). Wheat roots infested with root lesion nematodes display sloughing of cortical and epidermal cells, degradation of lateral roots, and loss of root hairs (Vanstone et al. 1998). Overall, affected plants appear stunted with premature yellowing of older leaves, reduced tillering, and lower kernel weights (Smiley 2004). These symptoms are often confused with nutrient deficiencies (Taylor et al. 1999) or fungal root rots (Taheri et al. 1994).

The primary control for root lesion nematode is the deployment of resistant and/or tolerant wheat cultivars. Nematode resistance is defined as the inability of a plant to serve as host for nematode reproduction (Taylor et al. 2000). For root lesion nematodes, resistance is species specific. For *P. neglectus,* the only known resistance gene is *Rlnn1* found in the moderately resistant Australian cultivar, 'Excalibur' (Williams et al. 2002). Resistance to *P. thornei* was found in a single plant selection, GS50a, discovered in an Australian field of the susceptible winter wheat cultivar, 'Gatcher' (Zwart et al. 2004). Wheat may also display tolerance, which is defined as the host's ability to overcome damaging effects of feeding. Tolerance is independent from resistance (Trudgill 1991) and is usually identified through paired plot trials using the nematicide, Temik (Taylor 1997; Thompson and Clewett 1989; Vanstone et al. 1995; and Vanstone 1998). Tolerance and resistance are shown to be independent phenotypic characters and a superior cultivar would be one that displayed both tolerance and resistance to root lesion nematodes.

In Montana, there are 2.8 million hectares of low rainfall, annually cropped wheat acreage. This acreage has conditions similar to those reported in Utah, Idaho, Oregon and Washington (Hafez 1992; Nicol 1999; Smiley 2005b). From a survey of root lesion nematodes in Montana conducted in 2006 and 2007, damaging populations of *P. neglectus* were found in 13.5% of all fields examined, amounting to an estimated 378,000 hectares being potentially impacted statewide. The primary purpose of this study was to provide management tools for impacted growers through assessing the relative tolerance and resistance to *P. neglectus* among Montana's popular modern and historical wheat cultivars. The objectives were to 1) survey the tolerance and resistance of Montana's modern wheat cultivars and 2) compare the relative tolerance and resistance of modern versus historical cultivars.

Methods and Materials

Greenhouse Resistance Testing

Resistance was evaluated for eight modern and six historical cultivars (Table 3). Two Australian cultivars were used as susceptible (Machete) and resistant controls (Excalibur). For each cultivar, three seeds were planted into each of six, 15cm diameter pots lined with a polyurethane bag containing 800g of a pasteurized soil mixture (1:1, sand: field soil (Amsterdam silty clay loam)). Each pot was then surface inoculated with 500 adult *P. neglectus* nematodes. Nematodes and seeds were then covered with an additional 200g of pasteurized soil. The source of inoculum came from nematodes produced by open pot culture in the greenhouse using the wheat cultivar, 'Gatcher' (O'Reilly and Thompson 1993). Planted pots were then watered, fertilized with Peter's 20-20-20 General Purpose N-P-K plant food at 0.25 g per liter of water, and arranged into six complete randomized blocks. Watering was assessed on a daily basis to maintain soil water at field capacity. At the second leaf stage, plants were thinned to one plant per pot.

Two trials were conducted for resistance evaluations with the first trial being planted on May 28, 2007 and the second trial followed on June 20, 2007. These experiments were sampled 12 weeks after planting for measurements of plant height, tiller number, biomass, and enumeration of nematode populations. To determine nematode populations for each pot, root tissue and soil were mixed by hand and a 200g sample was taken. Nematodes were extracted from the soil-root samples following a modified Whitehead tray method (Johnson et al. 2007). Final nematode populations were then determined using a Chalex counting chamber (Chalex Corporation, Wallowa, OR) and multiplication rates calculated as the ratio of final nematode population to initial nematode population.

Tolerance Trials

Nematode tolerance trials were conducted at two locations having known populations of *P. neglectus*. The first site, the Arthur H. Post Research Farm (Bozeman, MT) had low populations of *P. neglectus* (1108 *P. neglectus*/kg dry soil). The second site, a field in north central Montana, near Ulm, contained high populations of *P. neglectus* (3729 *P. neglectus*/kg dry soil). Soil at both sites consisted of silty clay loam (USDA 2007) and both sites were annually cropped to winter wheat.

For the Ulm site, 18 cultivars were evaluated for tolerance along with Australian controls (Table 4) (Smiley 2005c; Vanstone and Nicol 1993). For tolerance evaluations, cultivars were planted in paired plots (with and without nematicide) arranged in six randomized complete blocks. For nematicide treated plots, a granular formula of Temik (Temik 15G™, Bayer Crop Science, Research Triangle Park, NC) was applied 1" under the seed at a rate of 4.5 kg a.i/ha. Research plots were four 3 m rows planted with 25 cm spacing. Over the duration of the experiment, plots were maintained following best management practices. Plant vigor scores were taken several times throughout the growing season. Prior to statistical analysis, yield data was translated into a tolerance index by dividing the yields from untreated plots by the yield from the Temik treated plots and multiplying by 100. Ulm plots were planted on May 2, 2007 and the entire plots were harvested for yield on August 8, 2007.

The experimental design for the Bozeman trial was the same as that for Ulm, except that due to available space, 16 cultivars were evaluated plus Australian controls and only the middle two rows were harvested for yield (Table 4). Planting in Bozeman occurred on May 1, 2007 and harvest occurred on August 14, 2007.

Statistical Analysis

Data from both field and greenhouse trials were analyzed with blocking to remove positional effects using analysis of variance (SAS Institute 1988). If analysis of variance results showed significant cultivar differences ($p<0.05$) statistical separations were determined using least significant differences (LSD) ($p=0.05$). To compare the relative performance of old and new cultivars a statistical contrast was used (MacAnova 2006).

Results

Greenhouse Resistance Testing

Greenhouse evaluation of cultivars revealed nematode multiplication factors ranging from 1.7 to 7.9 for trial 1 and from 0.5 to 2.7 for trial 2 (Table 3). A Bartlett's test of homogeneity conducted, showed variances between trials to be unequal; therefore, results were not combined between trials ($p= 0.01$). No significant differences were seen among cultivars in trial 1 (F test, $p=0.1$) but significant differences were evident for trial 2 (F test, $p <0.001$). A statistical contrast between historic and modern cultivars conducted for trial 2 showed no significant differences in resistance between groups ($p=0.06$). For both trials, the historical cultivar Ceres performed comparable in suppressing nematode numbers to the resistant control, Excalibur (Figure 1A and B).

A Spearman rank correlation showed a modest correlation between the two experimental results ($R^2 = 0.34$, $p = 0.01$).

Table 3. Multiplication factors (Rf= final population/initial population) for 16 of Montana's modern and historic spring wheat cultivars as determined by greenhouse evaluations. Historic cultivars are listed in bold. [a]No significant differences (F test, $p=0.11$). [b]Significantly different (F test, $p <0.001$). [c]Fisher's LSD = 0.8. [d]Statistical contrasts between historic and modern cultivars for experiment 2 showed no significant differences ($p=0.06$). [e]Susceptible check. [f]Resistant check.

Cultivar	Rf Trial 1[a]	Rf Trial 2[b,c,d]
Fortuna	6.9	2.4
Marquis	5.3	0.9
Thatcher	4.9	1.9
Newana	3.9	0.7
Rushmore	3.4	0.9
Ceres	2.4	0.5
Hank	7.9	2.7
Conan	5.9	2.2
McNeal	5.6	0.8
Choteau	5.0	1.7
Outlook	4.8	1.6
Scholar	4.0	1.3
Vida	3.5	1.3
Reeder	3.0	1.0
Machete[e]	3.8	1.1
Excalibur[f]	1.7	1.1

Figure 4A

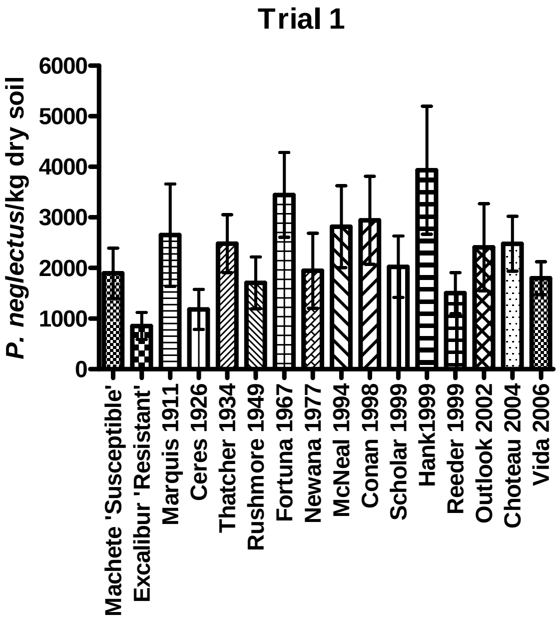
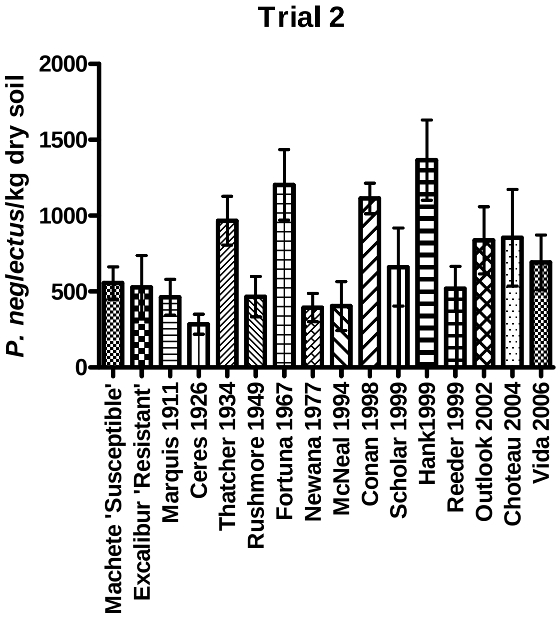


Figure 4B



Figures 4A and 4B. Final root lesion nematode populations (*P. neglectus*) in greenhouse trial 1 (4A) and trial 2 (4B) for 16 of Montana's historic and modern spring wheat cultivars. No significant differences were detected for experiment 1(F test, $p=0.11$). Significant differences were detected in experiment 2 (F test, $p<0.001$)(LSD= 0.8).

Tolerance Trials

For the Bozeman location, tolerance values ranged from 99 to 129 (Table 4). Only one cultivar, Rushmore showed an improvement in yields due to Temik application. On average, Temik application resulted in a 7.3% yield reduction. For the Ulm location, tolerance indexes ranged from 74 to 123 (Table 4). Eight cultivars showed improved yields from the Temik application. Yields were decreased by application of Temik an average of 0.38. Spearman rank correlation showed no significant correlations between trial locations ($R^2 < 0.001$, $p=0.97$). Ceres, McNeal, and Outlook maintained a relatively high degree of tolerance at both sites but no cultivar showed consistent susceptibility. Hank and Conan, though only tested at the Ulm site, showed very low tolerance to *P. neglectus*.

Table 4. Tolerance indexes for Montana's modern and historic spring wheat cultivars as determined by paired plot trials conducted in Bozeman and Ulm, Montana. Historic cultivars are bolded. [a]Yields are in kg/hectare, [b]Tolerance index equals paired plot ratio of yield for untreated plot divided by yield of plot treated with the nematicide, Temik 15G™. [c]No significant differences (*p=0.04*). [d]No significant differences (*p=0.63*). [e]Susceptible check. [f]Resistant check.

Cultivar	Bozeman Mean Untreated Yield[a]	Bozeman Tolerance Index[bc]	Ulm Mean Untreated Yield[a]	Ulm Tolerance Index[bd]
Thatcher	2002	129	527	78
Marquis	1474	114	388	94
Newana	1765	114	991	99
Fortuna	2120	103	679	103
Ceres	1560	103	712	102
Rushmore	1872	99	773	111
Vida	2933	117	721	86
MT1015	2917	110	NA	NA
Choteau	2927	107	724	96
Scholar	2373	104	945	109
Outlook	2561	104	1006	112
Reeder	2895	103	488	84
McNeal	2325	102	1124	112
Sunstate	2464	101	NA	NA
Conan	NA	NA	794	93
Hank	NA	NA	773	74
Alsen	NA	NA	433	104
Ernest	NA	NA	619	105
Machete[e]	2190	106	424	122
Excalibur[f]	2502	102	236	123

Discussion

In both greenhouse trials, Ceres suppressed nematode populations similar to or better than the resistant control, Excalibur. Ceres is a historic cultivar released by North Dakota in 1925 (Jenkins 1951) as a response to a stem rust epidemic. Based on its response in greenhouse trials, Ceres may represent a new source of nematode resistance. Identifying the location of its resistance within the genome will be necessary for breeding purposes. At this time, the only known resistance to *P. neglectus* is *Rlnn1* located on the long arm of chromosome 7a (Williams 2002). If confirmed through additional testing, Ceres' resistance would provide an important new genetic resource for management of root lesion nematodes in commercially available lines.

Temik applications resulted in considerable phytotoxicity in field trials at both the Bozeman and Ulm locations. Measuring tolerance was unattainable in these studies due to the adverse effects of Temik. Based on nematode response curves (data not presented) receiving a similar response from untreated plots would require a minimum of 3000 nematodes/kg of soil. This brings into question Temik's value in tolerance trials as phytotoxic responses hamper tolerance evaluations (Taylor et al. 1999). Other nematicides and biological controls are available for controlling nematode populations and they may provide more accurate tolerance evaluations (Robbins et al. 1972; Samac and Kinkel 2001).

Modern breeding for dramatic increases in yield has narrowed the genetic base of many crops (Dubcovsky 2007; Reid et al. 2007) and it has been speculated that this has lead to Montana's contemporary cultivars being more susceptible and intolerant to nematode populations than their predecessors. Based on this study, there was no evidence that historical cultivars provided any more resistance/tolerance than modern cultivars. While the historic cultivar Ceres did display resistance, its presence should be viewed as an isolated incident and not a general pattern among historic versus modern cultivars. Therefore exploring historic pedigrees for nematode resistance should be no more productive than looking at modern germplasm.

Environmental variation within the greenhouse was a significant confounding factor for the resistance trials. Within the small greenhouse enclosures, fluctuating temperatures, air currents, and pests from outside the building and surrounding greenhouses were problematic during the summer months when these experiments were conducted. This is indicated by the significant variation detected among research blocks. Some of the environmental variation may be compensated for through the use of a Latin square experimental design but a less variable greenhouse environment would provide the best solution. The greenhouse environment may be controlled through the use of heating/cooling mats, arranging experiments around air currents, and scheduling experiments during the less extreme seasons of fall, spring, and winter. It is important to note that the summer of 2007 had record breaking high temperatures, which negatively impacted nematode reproduction (Acosta 1979; Vanstone and Nicol 1993). High summer temperatures are uncommon in the Bozeman area and do not reflect what would be normally expected.

Sites selected for tolerance trials were poor. Nematode numbers at the Bozeman location were low which limited that trial from accurately measuring nematode tolerances. The Ulm site, while having large numbers of nematodes, had significant problems with variable nematode distribution and low moisture levels. Both sites were selected based on results of previous samples but were not extensively sampled prior to planting. More extensive sampling may have lead to better site selection or would have given pre-plant nematode populations that could be later included in the analyses. While better sampling may have accommodated some of the problems experienced, larger plot sizes would have reduced variation due to uneven nematode distributions and increased the ability to distinguish differences among cultivars.

This study revealed a potentially new source of nematode resistance and brought into question the use of Temik in tolerance evaluations. From greenhouse trials, the historic cultivar Ceres provided control equivalent to the moderately resistant cultivar, Excalibur. Ceres may represent only the second known source of nematode resistance, which would prove valuable to breeding programs anywhere *P. neglectus* impacts wheat. Due to Temik sensitivity, tolerance data obtained from these trials may be unreliable and better experimental designs should be explored. This research represents the beginning of nematode tolerance and resistance screening for Montana. Since root lesion nematodes are an important pest for Montana’s winter wheat, it is expected that additional trials will be conducted to evaluate resistance and tolerance among Montana’s winter wheat cultivars.

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CHAPTER 4

CONCLUSIONS

This is the first report of *Pratylenchus neglectus* in the state of Montana. For other wheat growing regions, damage thresholds for *P. neglectus* are reported at 2500 nematodes/kg of soil (Smiley et al. 2005b; Vanstone et al. 1998). Field sites in Montana where *P. neglectus* populations have exceeded this damage threshold are primarily in north central Montana and primarily in winter wheat. With a two-year average of 13.5% of sampled fields exceeding this threshold, estimated impact acreage for Montana would amount to 148 thousand hectares. In the northeast corner of Montana where low or no populations of root lesion nematode were detected, winter wheat is either not typically grown or grown in rotation with safflower, flax, and field peas, crops that are not host to *P. neglectus* (Smiley 2005b).

Finding higher populations of *P. neglectus* in fields following a winter wheat crop than a spring wheat crop in 2006 was unexpected since there have been fewer reports of injury in winter wheat than spring wheat (Mojahedi and Santo 1992). Studies in Oregon show significant negative correlations between grain yield and spring populations of *P. neglectus* for spring wheat. For these studies, yield losses of 36% were reported (Smiley 2005c). Relationships between spring nematode populations and yield losses have been confirmed for both spring and winter wheat in preliminary studies conducted in Montana (data not shown). Higher nematode populations in winter wheat are probably due to a longer growing season and overall cooler soil temperatures, optimal for *P. neglectus* reproduction.

No *Pratylenchus thornei* was found in any of the examined samples. The distribution of *P. thornei* in North America extends from the state of California: north to Washington state, east to Colorado state, and farther northeast into southern Ontario (Yu 1997). The absence of *P. thornei* might be interpreted that it simply has not been introduced into Montana at this time. Until now, *P. neglectus* and *P. thornei* had not been reported in Montana. Lack of *P. thornei* might be due to previous absence of the nematodes from Montana or limiting attributes of Montana's environment keeping this particular species from surviving here. Soil texture is considered a limiting factor for *P. thornei* colonization. However, examination of soil types for the majority of sampled sites consisted of silty clay loam or clay loam (data not shown), preferred soil types for *P. thornei* (Thompson 2000; Vanstone and Nicol 1993).

In 2007, a resampling of 60 fields showed no correlation between samples taken in consecutive years. This indicates that sampling results for individual fields across years are independent. There are several factors that may explain this. Fields in Montana typically exceed 200 hectares. Data from this study suggest sampling protocols used for this study are inadequate for measuring entire field populations and that returning to fields without specific locations provide considerable variation. An additional explanation is that field populations of the nematode show considerable fluctuations over time and previous field history was a factor in sampled populations.

Stunt nematode populations were consistent during both years. These results are similar to a recent survey of plant parasitic nematodes that concluded factors such as tillage, crop type, and watering had no effect on stunt nematode populations (Strausbaugh 2004). For fields not containing root lesion nematodes, the high incidence of

Tylenchorhynchus amongst soil samples acted as a positive control indicating soil samples were properly handled and were effective. The high levels and wide distribution of stunt nematode suggest these nematodes may be an additional concern for Montana's wheat producers.

This study has established the predominant species of root lesion nematode, *Pratylenchus neglectus*, is present in the state of Montana and is of concern to growers. Screening for tolerant and resistant varieties of winter and spring wheat to *Pratylenchus neglectus* is underway, along with, establishing predictive values for yield losses in important Montana small grain varieties. Due to a lack of other controls for root lesion nematode, resistant lines will become an essential component for grower management practices. There is little estimation as to why *P. thornei* did not occur in the study and requires further research to determine if introduction of the pest is avoidable. Occurrence of stunt nematode was extensive, but its importance is not well understood. Given its prevalence, its interaction and pathogenicity with wheat as a pest should be further investigated.

In both greenhouse trials, Ceres suppressed nematode populations similar to or better than the resistant control, Excalibur. Ceres is a historic cultivar released by North Dakota in 1925 (Jenkins 1951) as a response to a stem rust epidemic. Based on its response in greenhouse trials, Ceres may represent a new source of nematode resistance. Identifying the location of its resistance within the genome will be necessary for breeding purposes. At this time, the only known resistance to *P. neglectus* is *Rlnn1* located on the long arm of chromosome 7a (Williams 2002). If confirmed through additional testing, Ceres' resistance would provide an important new genetic resource for management of root lesion nematodes in commercially available lines.

Temik applications resulted in considerable phytotoxicity in field trials at both the Bozeman and Ulm locations. Measuring tolerance was unattainable due to adverse effects of the Temik. Based on nematode response curves (data not presented) receiving a similar response from untreated plots would require a minimum of 3000 nematodes/kg of soil. This brings into question Temik's value in tolerance trials as phytotoxic responses hamper tolerance evaluations (Taylor et al. 1999). Other nematicides and biological controls are available for controlling nematode populations and they may provide more accurate tolerance evaluations (Robbins et al. 1972; Samac and Kinkel 2001).

Modern breeding for dramatic increases in yield has narrowed the genetic base of many crops (Dubcovsky 2007; Reid et al. 2007) and it has been speculated that this has lead to Montana's contemporary cultivars being more susceptible and intolerant to nematode populations than their predecessors. Based on this study, there was no evidence that historical cultivars provided any more resistance/tolerance than modern cultivars. While the historic cultivar Ceres did display resistance, its presence should be viewed as an isolated incident and not a general pattern among historic versus modern cultivars. Therefore exploring historic pedigrees for nematode resistance should be no more productive than looking at modern germplasm.

Environmental variation within the greenhouse was a significant confounding factor for the resistance trials. Within the small greenhouse enclosures, fluctuating temperatures, air currents, and pests from outside the building and surrounding greenhouses were problematic during the summer months when these experiments were conducted. This is indicated by the significant variation detected among research blocks. Some of the environmental variation may be compensated for through the use of a Latin square experimental design but a less variable greenhouse environment would provide the best solution. The greenhouse environment may be controlled through the use of heating/cooling mats, arranging experiments around air currents, and scheduling experiments during the less extreme seasons of fall, spring, and winter. It is important to note that the summer of 2007 had record breaking high temperatures, which negatively impacted nematode reproduction (Acosta 1979; Vanstone and Nicol 1993). High summer temperatures are uncommon in the Bozeman area and do not reflect what would be normally expected.

Sites selected for tolerance trials were poor. Nematode numbers at the Bozeman location were low which limited that trial from accurately measuring nematode tolerances. The Ulm site, while having large numbers of nematodes, had significant problems with variable nematode distribution and low moisture levels. Both sites were selected based on results of previous samples but were not extensively sampled prior to planting. More extensive sampling may have lead to better site selection or would have given pre-plant nematode populations that could be later included in the analyses. While better sampling may have accommodated some of the problems experienced, larger plot sizes would have reduced variation due to uneven nematode distributions and increased the ability to distinguish differences among cultivars.

This study revealed a potentially new source of nematode resistance and brought into question the use of Temik in tolerance evaluations. From greenhouse trials, the historic cultivar Ceres provided control equivalent to the moderately resistant cultivar, Excalibur. Ceres may represent only the second known source of nematode resistance, which would prove valuable to breeding programs anywhere *P. neglectus* impacts wheat. Due to Temik sensitivity, tolerance data obtained from these trials may be unreliable and better experimental designs should be explored. This research represents the beginning of nematode tolerance and resistance screening for Montana. Since root lesion nematodes are an important pest for Montana’s winter wheat, it is expected that additional trials will be conducted to evaluate resistance and tolerance among Montana’s winter wheat cultivars.

APPENDICES

APPENDIX A

BOZEMAN TOLERANCE TRIAL VIGOR DATA

Appendix A. Bozeman Tolerance Trial Data: Data is given by cultivar. Cultivars are arranged by their replication number and their treatment. Treatments are given as an untreated check (c) or as Temik (t). Row numbers for vigor data are also given.   Two vigor scores were taken during the growing season. Score 1 was taken June 20th, and Score 2 was taken July 22, 2007. The scores range from 0-5, 5 visually ranking superior in growth and uniformity. Scores reflect a comparison of varieties and their side-by-side plots. Height measurements in cm were taken July 22, 2007.

BOZEMAN TOLERANCE TRIAL VIGOR DATA

Cultivar	Rep	Treatment	Row#	Score 1	Score 2	Height cm
Marquis	1	c	6001	3	4	100
Marquis	1	t	6002	3	4	103
Ceres	1	c	6003	4	5	110
Ceres	1	t	6004	4	5	107
Thatcher	1	c	6005	4	3	102
Thatcher	1	t	6006	2	4	96
Rushmore	1	c	6007	4	3	104
Rushmore	1	t	6008	3	3	100
Fortuna	1	c	6101	3	4	98
Fortuna	1	t	6102	2	4	102
Newana	1	c	6103	2	3	74
Newana	1	t	6104	2	3	71
Outlook	1	c	6105	2	3	79
Outlook	1	t	6106	2	3	85
McNeal	1	c	6107	2	4	77
McNeal	1	t	6108	2	4	75
Scholar	1	c	6201	3	4	89
Scholar	1	t	6202	3	4	94
Vida	1	c	6203	3	2	84
Vida	1	t	6204	2	2	74
Reeder	1	c	6205	3	3	87
Reeder	1	t	6206	3	3	84
Choteau	1	c	6207	3	3	77
Choteau	1	t	6208	2	2	75
MT1015	1	c	6301	3	4	83
MT1015	1	t	6302	3	4	78
Sunstate	1	c	6303	2	3	82
Sunstate	1	t	6304	2	2	81
Excalibur	1	c	6305	2	2	64
Excalibur	1	t	6306	2	2	65
Machete	1	c	6307	2	2	63
Machete	1	t	6308	2	2	58
Thatcher	2	c	6401	3	4	94
Thatcher	2	t	6402	2	3	96
Outlook	2	c	6403	2	3	77
Outlook	2	t	6404	2	3	81
Vida	2	c	6405	3	4	84
Vida	2	t	6406	2	3	87
Choteau	2	c	6407	2	4	80
Choteau	2	t	6408	2	3	82
Machete	2	c	6501	2	2	66
Machete	2	t	6502	2	2	60
Scholar	2	c	6503	2	4	90
Scholar	2	t	6504	2	4	95
Fortuna	2	c	6505	4	5	96
Fortuna	2	t	6506	3	4	93

Newana	2	c	6507	3	3	69
Newana	2	t	6508	2	3	67
Reeder	2	c	6601	3	4	78
Reeder	2	t	6602	3	4	82
Ceres	2	c	6603	2	5	104
Ceres	2	t	6604	2	5	110
Rushmore	2	c	6605	2	5	97
Rushmore	2	t	6606	3	5	105
MT1015	2	c	6607	2	3	77
MT1015	2	t	6608	1	3	72
Sunstate	2	c	6701	2	3	68
Sunstate	2	t	6702	2	3	79
Excalibur	2	c	6703	2	2	64
Excalibur	2	t	6704	2	2	65
McNeal	2	c	6705	2	3	78
McNeal	2	t	6706	2	3	80
Marquis	2	c	6707	2	4	105
Marquis	2	t	6708	2	3	104
Reeder	3	c	6801	3	4	75
Reeder	3	t	6802	2	4	74
Rushmore	3	c	6803	3	5	85
Rushmore	3	t	6804	3	4	98
Marquis	3	c	6805	2	4	95
Marquis	3	t	6806	2	3	110
Excalibur	3	c	6807	2	3	65
Excalibur	3	t	6808	2	3	64
Machete	3	c	6901	2	3	61
Machete	3	t	6902	2	3	60
Thatcher	3	c	6903	4	5	98
Thatcher	3	t	6904	3	4	96
Scholar	3	c	6905	3	4	95
Scholar	3	t	6906	2	4	90
Vida	3	c	6907	3	4	82
Vida	3	t	6908	2	3	78
Newana	3	c	7001	3	3	67
Newana	3	t	7002	3	3	73
McNeal	3	c	7003	2	3	76
McNeal	3	t	7004	3	4	77
Outlook	3	c	7005	2	3	78
Outlook	3	t	7006	2	3	76
MT1015	3	c	7007	3	3	75
MT1015	3	t	7008	2	3	80
Fortuna	3	c	7101	4	5	100
Fortuna	3	t	7102	5	5	96
Ceres	3	c	7103	3	5	104
Ceres	3	t	7104	3	5	103
Choteau	3	c	7105	3	4	78
Choteau	3	t	7106	3	4	73
Sunstate	3	c	7107	2	3	82
Sunstate	3	t	7108	3	3	80

Scholar	4	c	7201	4	4	98
Scholar	4	t	7202	4	4	93
Excalibur	4	c	7203	2	2	63
Excalibur	4	t	7204	2	2	68
Outlook	4	c	7205	2	3	74
Outlook	4	t	7206	2	3	77
Machete	4	c	7207	2	3	60
Machete	4	t	7208	2	3	62
MT1015	4	c	7301	2	3	88
MT1015	4	t	7302	2	3	81
Marquis	4	c	7303	3	4	92
Marquis	4	t	7304	2	3	101
Fortuna	4	c	7305	4	4	91
Fortuna	4	t	7306	4	5	93
Newana	4	c	7307	2	3	62
Newana	4	t	7308	3	3	66
Sunstate	4	c	7401	2	3	74
Sunstate	4	t	7402	3	3	75
Reeder	4	c	7403	4	4	77
Reeder	4	t	7404	3	3	81
Choteau	4	c	7405	3	4	68
Choteau	4	t	7406	2	4	74
McNeal	4	c	7407	3	3	73
McNeal	4	t	7408	2	3	73
Ceres	4	c	7501	4	5	94
Ceres	4	t	7502	4	4	97
Thatcher	4	c	7503	4	5	95
Thatcher	4	t	7504	3	4	92
Vida	4	c	7505	3	3	73
Vida	4	t	7506	2	3	76
Rushmore	4	c	7507	4	5	97
Rushmore	4	t	7508	4	5	106
Vida	5	c	7601	3	3	76
Vida	5	t	7602	2	2	78
Fortuna	5	c	7603	4	4	98
Fortuna	5	t	7604	4	4	100
Excalibur	5	c	7605	2	3	64
Excalibur	5	t	7606	1	2	54
MT1015	5	c	7607	3	3	70
MT1015	5	t	7608	3	3	85
Ceres	5	c	7701	5	4	99
Ceres	5	t	7702	3	3	97
Sunstate	5	c	7703	3	4	80
Sunstate	5	t	7704	3	3	74
Outlook	5	c	7705	3	3	57
Outlook	5	t	7706	3	3	74
Reeder	5	c	7707	4	1	78
Reeder	5	t	7708	3	1	71
Marquis	5	c	7801	3	4	108
Marquis	5	t	7802	3	3	110

Thatcher	5	c	7803	3	3	82
Thatcher	5	t	7804	2	2	84
Scholar	5	c	7805	3	3	85
Scholar	5	t	7806	2	2	79
McNeal	5	c	7807	2	1	79
McNeal	5	t	7808	2	1	78
Choteau	5	c	7901	2	3	69
Choteau	5	t	7902	2	3	69
Newana	5	c	7903	2	3	65
Newana	5	t	7904	2	3	60
Rushmore	5	c	7905	3	3	94
Rushmore	5	t	7906	3	3	93
Machete	5	c	7907	2	2	62
Machete	5	t	7908	1	2	49
McNeal	6	c	8001	2	2	72
McNeal	6	t	8002	1	1	69
Reeder	6	c	8003	2	3	80
Reeder	6	t	8004	2	3	78
Excalibur	6	c	8005	2	2	60
Excalibur	6	t	8006	2	2	64
Outlook	6	c	8007	2	3	73
Outlook	6	t	8008	1	1	72
Marquis	6	c	8101	2	3	103
Marquis	6	t	8102	3	3	98
MT1015	6	c	8103	2	2	75
MT1015	6	t	8104	2	3	72
Choteau	6	c	8105	2	3	76
Choteau	6	t	8106	2	4	66
Scholar	6	c	8107	2	4	79
Scholar	6	t	8108	2	3	86
Vida	6	c	8201	2	4	79
Vida	6	t	8202	2	3	68
Fortuna	6	c	8203	5	4	89
Fortuna	6	t	8204	4	4	94
Machete	6	c	8205	2	3	62
Machete	6	t	8206	2	3	56
Thatcher	6	c	8207	3	3	88
Thatcher	6	t	8208	2	2	85
Vida	6	c	8301	3	3	77
Vida	6	t	8302	3	3	73
Newana	6	c	8303	2	2	66
Newana	6	t	8304	2	2	61
Rushmore	6	c	8305	4	4	104
Rushmore	6	t	8306	4	4	96
Ceres	6	c	8307	3	3	102
Ceres	6	t	8308	3	3	101

APPENDIX B

ULM TOLERANCE TRIAL VIGOR DATA

Appendix B. Ulm Tolerance Trial Data: Data is given by cultivar. Cultivars are arranged by their replication number and their treatment. Treatments are given as an untreated check (c) or as Temik (t). Row numbers for vigor data are also given. Two vigor scores were taken during the growing season. Score 1 was taken June 21th, and Score 2 was taken July 11, 2007. The scores range from 0-5, 5 visually ranking superior in growth and uniformity. Scores reflect a comparison of varieties and their side-by-side plots. Height measurements in cm were taken July 21, 2007.

ULM TOLERANCE TRIAL VIGOR DATA

Cultivar	Rep	Treatment	Row#	Score1	Score2	Height cm
Alsen	1	c	129	2	3	40
Alsen	1	t	130	2	3	39
Alsen	2	c	227	2	2	41
Alsen	2	t	228	2	2	47
Alsen	3	c	307	2	2	32
Alsen	3	t	308	2	2	37
Alsen	4	c	433	2	3	39
Alsen	4	t	434	2	3	37
Alsen	5	c	505	2	2	33
Alsen	5	t	506	2	1	30
Alsen	6	c	605	2	2	33
Alsen	6	t	606	2	3	32
Ceres	1	c	103	2	3	45
Ceres	1	t	104	3	3	44
Ceres	2	c	219	5	5	60
Ceres	2	t	220	5	5	57
Ceres	3	c	327	3	1	41
Ceres	3	t	328	4	1	40
Ceres	4	c	425	3	3	44
Ceres	4	t	426	4	2	40
Ceres	5	c	535	5	5	64
Ceres	5	t	536	5	5	59
Ceres	6	c	631	5	4	43
Ceres	6	t	632	4	4	50
Choteau	1	c	123	2	2	38
Choteau	1	t	124	2	3	44
Choteau	2	c	207	2	1	28
Choteau	2	t	208	2	1	30
Choteau	3	c	329	2	1	36
Choteau	3	t	330	2	1	37
Choteau	4	c	421	3	3	35
Choteau	4	t	422	3	3	41
Choteau	5	c	525	4	4	42
Choteau	5	t	526	4	3	38
Choteau	6	c	613	2	1	34
Choteau	6	t	614	2	2	35
Conan	1	c	125	2	4	49
Conan	1	t	126	2	4	49
Conan	2	c	223	3	3	41
Conan	2	t	224	2	2	40
Conan	3	c	333	2	1	38
Conan	3	t	334	2	1	42
Conan	4	c	409	3	2	36
Conan	4	t	410	2	2	38
Conan	5	c	533	3	3	46

Conan	5	t	534	2	4	64
Conan	6	c	611	2	1	30
Conan	6	t	612	2	2	33
Ernest	1	c	127	2	4	45
Ernest	1	t	128	2	3	43
Ernest	2	c	225	2	2	35
Ernest	2	t	226	2	2	39
Ernest	3	c	331	2	2	35
Ernest	3	t	332	2	2	28
Ernest	4	c	417	3	3	38
Ernest	4	t	418	3	2	35
Ernest	5	c	511	1	2	31
Ernest	5	t	512	2	2	31
Ernest	6	c	625	3	3	40
Ernest	6	t	626	2	3	37
Excalibur	1	c	133	2	2	34
Excalibur	1	t	134	2	2	32
Excalibur	2	c	205	1	2	21
Excalibur	2	t	206	1	2	22
Excalibur	3	c	315	3	2	24
Excalibur	3	t	316	3	2	40
Excalibur	4	c	403	2	2	24
Excalibur	4	t	404	2	1	23
Excalibur	5	c	509	2	1	21
Excalibur	5	t	510	2	1	18
Excalibur	6	c	609	2	1	20
Excalibur	6	t	610	2	1	18
Fortuna	1	c	109	3	3	42
Fortuna	1	t	110	3	3	44
Fortuna	2	c	213	3	4	49
Fortuna	2	t	214	2	3	47
Fortuna	3	c	325	3	2	39
Fortuna	3	t	326	3	2	43
Fortuna	4	c	413	3	3	44
Fortuna	4	t	414	3	3	45
Fortuna	5	c	503	3	2	35
Fortuna	5	t	504	3	2	34
Fortuna	6	c	619	4	3	45
Fortuna	6	t	620	4	3	45
Hank	1	c	131	2	3	39
Hank	1	t	132	3	4	45
Hank	2	c	209	3	3	33
Hank	2	t	210	3	3	41
Hank	3	c	309	4	3	39
Hank	3	t	310	5	3	52
Hank	4	c	407	4	2	31
Hank	4	t	408	4	2	33
Hank	5	c	531	2	2	43
Hank	5	t	532	3	4	43
Hank	6	c	621	4	2	32

Hank	6	t	622	4	2	34
Machete	1	c	135	2	2	34
Machete	1	t	136	2	2	30
Machete	2	c	217	2	3	44
Machete	2	t	218	2	3	45
Machete	3	c	323	3	3	40
Machete	3	t	324	3	3	40
Machete	4	c	431	2	3	34
Machete	4	t	432	2	3	44
Machete	5	c	507	2	1	21
Machete	5	t	508	1	1	18
Machete	6	c	607	2	2	37
Machete	6	t	608	2	2	26
Marquis	1	c	101	2	2	40
Marquis	1	t	102	2	2	39
Marquis	2	c	231	2	3	40
Marquis	2	t	232	1	3	41
Marquis	3	c	305	3	3	38
Marquis	3	t	306	3	2	32
Marquis	4	c	411	2	3	41
Marquis	4	t	412	2	3	42
Marquis	5	c	517	3	2	43
Marquis	5	t	518	2	2	38
Marquis	6	c	633	4	4	47
Marquis	6	t	634	4	4	49
McNeal	1	c	115	2	3	55
McNeal	1	t	116	2	4	55
McNeal	2	c	229	3	3	45
McNeal	2	t	230	3	3	43
McNeal	3	c	319	4	5	50
McNeal	3	t	320	4	5	53
McNeal	4	c	423	3	4	45
McNeal	4	t	424	4	3	47
McNeal	5	c	523	3	5	58
McNeal	5	t	524	3	4	37
McNeal	6	c	601	4	3	35
McNeal	6	t	602	4	3	40
Newana	1	c	111	2	3	42
Newana	1	t	112	2	3	40
Newana	2	c	215	2	4	44
Newana	2	t	216	3	4	47
Newana	3	c	317	3	3	40
Newana	3	t	318	3	3	52
Newana	4	c	415	2	3	42
Newana	4	t	416	3	3	41
Newana	5	c	527	3	4	38
Newana	5	t	528	3	3	48
Newana	6	c	627	3	3	40
Newana	6	t	628	4	3	39
Outlook	1	c	113	2	4	49

Outlook	1	t	114	2	3	50
Outlook	2	c	203	2	3	34
Outlook	2	t	204	2	3	32
Outlook	3	c	321	3	5	46
Outlook	3	t	322	3	5	40
Outlook	4	c	405	3	2	35
Outlook	4	t	406	3	1	24
Outlook	5	c	513	3	3	35
Outlook	5	t	514	3	3	32
Outlook	6	c	635	3	3	43
Outlook	6	t	636	3	4	41
Reeder	1	c	121	2	3	38
Reeder	1	t	122	2	2	39
Reeder	2	c	233	4	3	41
Reeder	2	t	234	3	4	40
Reeder	3	c	301	4	3	35
Reeder	3	t	302	3	3	50
Reeder	4	c	419	3	2	41
Reeder	4	t	420	3	4	38
Reeder	5	c	515	3	2	37
Reeder	5	t	516	3	3	40
Reeder	6	c	603	3	2	35
Reeder	6	t	604	3	2	36
Rushmore	1	c	107	2	3	41
Rushmore	1	t	108	3	3	41
Rushmore	2	c	221	4	4	59
Rushmore	2	t	222	3	3	43
Rushmore	3	c	303	4	3	49
Rushmore	3	t	304	3	2	42
Rushmore	4	c	435	3	3	44
Rushmore	4	t	436	3	2	48
Rushmore	5	c	529	5	3	45
Rushmore	5	t	530	5	3	38
Rushmore	6	c	629	5	3	46
Rushmore	6	t	630	5	3	45
Scholar	1	c	117	3	5	57
Scholar	1	t	118	3	4	53
Scholar	2	c	211	4	4	46
Scholar	2	t	212	3	4	52
Scholar	3	c	313	4	4	48
Scholar	3	t	314	4	4	24
Scholar	4	c	401	3	4	39
Scholar	4	t	402	3	4	42
Scholar	5	c	521	4	5	59
Scholar	5	t	522	3	4	46
Scholar	6	c	615	3	3	46
Scholar	6	t	616	3	3	44
Thatcher	1	c	105	2	2	38
Thatcher	1	t	106	2	3	38
Thatcher	2	c	201	3	3	38

Thatcher	2	t	202	2	3	37
Thatcher	3	c	311	4	3	49
Thatcher	3	t	312	3	3	49
Thatcher	4	c	427	3	2	42
Thatcher	4	t	428	2	2	37
Thatcher	5	c	519	3	2	38
Thatcher	5	t	520	2	5	55
Thatcher	6	c	623	3	3	45
Thatcher	6	t	624	2	4	42
Vita	1	c	119	2	3	40
Vita	1	t	120	2	3	41
Vita	2	c	235	4	3	44
Vita	2	t	236	3	3	35
Vita	3	c	335	3	2	36
Vita	3	t	336	2	2	36
Vita	4	c	429	2	2	39
Vita	4	t	430	2	4	40
Vita	5	c	501	3	2	34
Vita	5	t	502	2	2	32
Vita	6	c	617	3	2	34
Vita	6	t	618	3	3	33

APPENDIX C

BOZEMAN RAW YIELD DATA

Appendix C. Yield data is arranged by cultivar, plot row number, and treatment (Temik plots (t) and the check (c) plots). Two yields from two rows were added together in the total yield column.

BOZEMAN RAW YIELD DATA

Cultivar	Row #	Yield1	Yield2	Treatment	Total Yield/g
Ceres	6003	166	178	c	344
Ceres	6603	150	142	c	292
Ceres	7103	150	155	c	305
Ceres	7501	162	155	c	317
Ceres	7701	165	125	c	290
Ceres	8307	101	92	c	193
Ceres	6004	176	140	t	316
Ceres	6604	156	130	t	286
Ceres	7104	180	153	t	333
Ceres	7502	158	132	t	290
Ceres	7702	129	166	t	295
Ceres	8308	74	91	t	165
Choteau	6207	266	281	c	547
Choteau	6407	288	275	c	563
Choteau	7105	266	279	c	545
Choteau	7405	285	305	c	590
Choteau	7901	268	266	c	534
Choteau	8105	243	247	c	490
Choteau	6208	291	280	t	571
Choteau	6408	216	249	t	465
Choteau	7106	288	289	t	577
Choteau	7406	310	249	t	559
Choteau	7902	243	212	t	455
Choteau	8106	222	191	t	413
Excalibur	6305	244	236	c	480
Excalibur	6703	241	190	c	431
Excalibur	6807	256	215	c	471
Excalibur	7203	221	226	c	447
Excalibur	7605	228	236	c	464
Excalibur	8005	247	250	c	497
Excalibur	6306	222	269	t	491
Excalibur	6704	208	248	t	456
Excalibur	6808	208	213	t	421
Excalibur	7204	224	225	t	449
Excalibur	7606	213	215	t	428
Excalibur	8006	231	251	t	482
Fortuna	6101	211	218	c	429
Fortuna	6505	184	200	c	384
Fortuna	7101	208	217	c	425
Fortuna	7305	219	202	c	421
Fortuna	7603	204	190	c	394
Fortuna	8203	160	155	c	315
Fortuna	6102	215	212	t	427

Fortuna	6506	182	162	t	344
Fortuna	7102	189	183	t	372
Fortuna	7306	194	204	t	398
Fortuna	7604	185	197	t	382
Fortuna	8204	179	185	t	364
Machete	6307	238	220	c	458
Machete	6501	204	220	c	424
Machete	6901	191	197	c	388
Machete	7207	261	221	c	482
Machete	7907	154	168	c	322
Machete	8205	184	187	c	371
Machete	6308	225	186	t	411
Machete	6502	213	202	t	415
Machete	6902	187	207	t	394
Machete	7208	191	223	t	414
Machete	7908	186	190	t	376
Machete	8206	157	126	t	283
Marquis	6001	143	132	c	275
Marquis	6707	135	133	c	268
Marquis	6805	155	149	c	304
Marquis	7303	125	119	c	244
Marquis	7801	137	146	c	283
Marquis	8101	145	127	c	272
Marquis	6002	137	114	t	251
Marquis	6708	108	113	t	221
Marquis	6806	141	130	t	271
Marquis	7304	112	117	t	229
Marquis	7802	124	98	t	222
Marquis	8102	127	122	t	249
McNeal	6107	258	232	c	490
McNeal	6705	232	251	c	483
McNeal	7003	226	208	c	434
McNeal	7407	251	215	c	466
McNeal	7807	188	187	c	375
McNeal	8001	152	193	c	345
McNeal	6108	262	247	t	509
McNeal	6706	238	188	t	426
McNeal	7004	269	211	t	480
McNeal	7408	237	200	t	437
McNeal	7808	181	188	t	369
McNeal	8002	191	118	t	309
MT1015	6301	304	313	c	617
MT1015	6607	219	258	c	477
MT1015	7007	302	295	c	597
MT1015	7301	250	268	c	518
MT1015	7607	271	260	c	531
MT1015	8103	262	255	c	517
MT1015	6302	270	255	t	525

MT1015	6608	196	238	t	434
MT1015	7008	243	281	t	524
MT1015	7302	227	249	t	476
MT1015	7608	255	216	t	471
MT1015	8104	305	200	t	505
Newana	6103	235	194	c	429
Newana	6507	160	175	c	335
Newana	7001	137	171	c	308
Newana	7307	206	167	c	373
Newana	7903	145	126	c	271
Newana	8303	128	125	c	253
Newana	6104	172	213	t	385
Newana	6508	164	165	t	329
Newana	7002	142	163	t	305
Newana	7308	143	112	t	255
Newana	7904	111	119	t	230
Newana	8304	122	94	t	216
Outlook	6105	259	258	c	517
Outlook	6403	259	262	c	521
Outlook	7005	242	257	c	499
Outlook	7205	242	242	c	484
Outlook	7705	231	200	c	431
Outlook	8007	208	199	c	407
Outlook	6106	285	214	t	499
Outlook	6404	255	257	t	512
Outlook	7006	205	260	t	465
Outlook	7206	239	288	t	527
Outlook	7706	214	215	t	429
Outlook	8008	157	156	t	313
Reeder	6205	321	278	c	599
Reeder	6601	247	275	c	522
Reeder	6801	270	268	c	538
Reeder	7403	283	283	c	566
Reeder	7707	273	268	c	541
Reeder	8003	246	217	c	463
Reeder	6206	280	288	t	568
Reeder	6602	252	239	t	491
Reeder	6802	235	274	t	509
Reeder	7404	291	290	t	581
Reeder	7708	246	250	t	496
Reeder	8004	246	239	t	485
Rushmore	6007	169	162	c	331
Rushmore	6605	168	166	c	334
Rushmore	6803	158	195	c	353
Rushmore	7507	209	180	c	389
Rushmore	7905	159	200	c	359
Rushmore	8305	165	160	c	325
Rushmore	6008	186	180	t	366

Rushmore	6606	180	153	t	333
Rushmore	6804	157	173	t	330
Rushmore	7508	170	197	t	367
Rushmore	7906	145	182	t	327
Rushmore	8306	196	177	t	373
Scholar	6201	223	247	c	470
Scholar	6503	201	259	c	460
Scholar	6905	242	250	c	492
Scholar	7201	251	230	c	481
Scholar	7805	183	192	c	375
Scholar	8107	197	172	c	369
Scholar	6202	233	259	t	492
Scholar	6504	234	182	t	416
Scholar	6906	220	190	t	410
Scholar	7202	264	256	t	520
Scholar	7806	183	168	t	351
Scholar	8108	165	167	t	332
Sunstate	6303	248	245	c	493
Sunstate	6701	245	210	c	455
Sunstate	7107	232	238	c	470
Sunstate	7401	237	206	c	443
Sunstate	7703	235	197	c	432
Sunstate	6304	253	250	t	503
Sunstate	6702	233	263	t	496
Sunstate	7108	228	219	t	447
Sunstate	7402	204	201	t	405
Sunstate	7704	200	213	t	413
Thatcher	6005	160	168	c	328
Thatcher	6401	192	184	c	376
Thatcher	6903	176	188	c	364
Thatcher	7503	166	281	c	447
Thatcher	7803	162	178	c	340
Thatcher	8207	197	182	c	379
Thatcher	6006	134	132	t	266
Thatcher	6402	182	128	t	310
Thatcher	6904	191	140	t	331
Thatcher	7504	138	172	t	310
Thatcher	7804	125	167	t	292
Thatcher	8208	107	112	t	219
Vida	6203	324	332	c	656
Vida	6405	319	270	c	589
Vida	6907	309	279	c	588
Vida	7505	260	256	c	516
Vida	7601	277	312	c	589
Vida	8201	229	221	c	450
Vida	8301	210	220	c	430
Vida	6204	251	326	t	577
Vida	6406	241	210	t	451

Vida	6908	252	226	t	478
Vida	7506	270	197	t	467
Vida	7602	207	272	t	479
Vida	8202	195	203	t	398
Vida	8302	218	178	t	396

APPENDIX D

ULM RAW YIELD DATA

Appendix D. Yield data is arranged by cultivar, plot row number, and treatment (Temik plots (t) and the check (c) plots).

ULM RAW YIELD DATA

Cultivar	Treatment	Row #	Yield/g
Alsen	c	129	211
Alsen	c	227	171
Alsen	c	307	76
Alsen	c	433	242
Alsen	c	505	81
Alsen	c	605	74
Alsen	t	130	217
Alsen	t	228	180
Alsen	t	308	82
Alsen	t	434	207
Alsen	t	506	53
Alsen	t	606	81
Ceres	c	103	134
Ceres	c	219	444
Ceres	c	327	29
Ceres	c	425	175
Ceres	c	535	427
Ceres	c	631	201
Ceres	t	104	158
Ceres	t	220	394
Ceres	t	328	47
Ceres	t	426	73
Ceres	t	536	433
Ceres	t	632	266
Choteau	c	123	254
Choteau	c	207	43
Choteau	c	329	72
Choteau	c	421	428
Choteau	c	525	539
Choteau	c	613	100
Choteau	t	124	396
Choteau	t	208	49
Choteau	t	330	60
Choteau	t	422	417
Choteau	t	526	444
Choteau	t	614	120
Conan	c	125	263
Conan	c	223	344
Conan	c	333	123
Conan	c	533	457
Conan	c	611	123
Conan	t	126	370
Conan	t	224	212
Conan	t	334	190
Conan	t	534	516
Conan	t	612	110
Conan	c	409	157

Ernest	c	127	406
Ernest	c	225	256
Ernest	c	331	113
Ernest	c	417	266
Ernest	c	511	170
Ernest	c	625	384
Ernest	t	128	308
Ernest	t	226	208
Ernest	t	332	172
Ernest	t	418	224
Ernest	t	512	180
Ernest	t	626	413
Excalibur	c	133	170
Excalibur	c	205	41
Excalibur	c	315	90
Excalibur	c	403	42
Excalibur	c	509	47
Excalibur	t	134	170
Excalibur	t	206	27
Excalibur	t	316	56
Excalibur	t	404	34
Excalibur	t	510	29
Excalibur	c	610	36
Fortuna	c	213	330
Fortuna	c	325	42
Fortuna	c	413	209
Fortuna	c	503	221
Fortuna	c	619	320
Fortuna	t	214	255
Fortuna	t	326	84
Fortuna	t	414	259
Fortuna	t	504	175
Fortuna	t	620	307
Hank	c	131	441
Hank	c	209	188
Hank	c	407	144
Hank	c	531	302
Hank	c	621	199
Hank	t	132	489
Hank	t	210	234
Hank	t	408	160
Hank	t	532	571
Hank	t	622	253
Hank	c	309	273
Machete	c	135	158
Machete	c	217	209
Machete	c	323	204
Machete	c	431	220
Machete	c	507	21
Machete	c	607	32

Machete	t	136	122
Machete	t	218	214
Machete	t	324	146
Machete	t	432	165
Machete	t	508	18
Machete	t	608	26
Marquis	c	101	77
Marquis	c	231	124
Marquis	c	305	104
Marquis	c	411	95
Marquis	c	517	148
Marquis	c	633	217
Marquis	t	102	89
Marquis	t	232	169
Marquis	t	306	93
Marquis	t	412	126
Marquis	t	518	97
Marquis	t	634	238
McNeal	c	115	255
McNeal	c	229	289
McNeal	c	319	487
McNeal	c	423	364
McNeal	c	523	625
McNeal	c	601	203
McNeal	t	116	347
McNeal	t	230	244
McNeal	t	320	493
McNeal	t	424	270
McNeal	t	524	422
McNeal	t	602	205
Newana	c	111	321
Newana	c	215	305
Newana	c	317	254
Newana	c	415	295
Newana	c	527	371
Newana	c	627	413
Newana	t	112	351
Newana	t	216	378
Newana	t	318	337
Newana	t	416	285
Newana	t	528	261
Newana	t	628	363
Outlook	c	113	399
Outlook	c	203	224
Outlook	c	321	549
Outlook	c	405	117
Outlook	c	513	218
Outlook	c	635	487
Outlook	t	114	331
Outlook	t	204	203

Outlook	t	322	460
Outlook	t	406	61
Outlook	t	514	239
Outlook	t	636	471
Reeder	c	121	124
Reeder	c	233	180
Reeder	c	301	176
Reeder	c	419	205
Reeder	c	515	166
Reeder	c	603	116
Reeder	t	122	111
Reeder	t	234	174
Reeder	t	302	195
Reeder	t	420	283
Reeder	t	516	268
Reeder	t	604	110
Rushmore	c	107	162
Rushmore	c	221	370
Rushmore	c	303	250
Rushmore	c	435	256
Rushmore	c	529	208
Rushmore	c	629	284
Rushmore	t	108	168
Rushmore	t	222	268
Rushmore	t	304	250
Rushmore	t	436	226
Rushmore	t	530	208
Rushmore	t	630	251
Scholar	c	117	405
Scholar	c	211	231
Scholar	c	313	285
Scholar	c	401	213
Scholar	c	521	568
Scholar	c	615	168
Scholar	t	118	360
Scholar	t	212	316
Scholar	t	314	256
Scholar	t	402	217
Scholar	t	522	369
Scholar	t	616	185
Thatcher	c	105	155
Thatcher	c	201	117
Thatcher	c	311	238
Thatcher	c	427	121
Thatcher	c	519	200
Thatcher	c	623	214
Thatcher	t	106	187
Thatcher	t	202	141
Thatcher	t	312	239
Thatcher	t	428	155

Thatcher	t	520	371
Thatcher	t	624	231
Vida	c	119	306
Vida	c	235	324
Vida	c	335	185
Vida	c	429	194
Vida	c	501	219
Vida	c	617	195
Vida	t	120	263
Vida	t	236	325
Vida	t	336	205
Vida	t	430	300
Vida	t	502	237
Vida	t	618	306

APPENDIX E

GREENHOUSE RESISTANCE DATA TRIAL 1

Appendix E. Greenhouse Resistance Data Trial 1: Data is arranged by cultivar and replication number. Data was recorded 12 weeks after planting and consists of biomass measurements, soil moisture, and final nematode populations. Biomass measurements include average tiller height, tiller number, and total biomass from crown up in g. Biomass was not taken for pots where plants had died during trials. Soil moisture was measured by drying 100 g of fresh soil at 70°C for 48 hrs. Final nematode populations are recorded in nematodes/kg dry soil.

GREENHOUSE RESISTANCE DATA TRIAL 1

Cultivar	Rep	Height	Tiller #	Biomass g	Soil Moisture	Final *Neglectus*
Ceres	1	63.1	4	8.4	89.46	1373
Ceres	2	52.6	5	8.85	92.14	2990
Ceres	3	60.5	4	7.21	94.41	1213
Ceres	4	42.1	8	10.74	94.02	604
Ceres	5	45.3	4	6.46	92.74	463
Ceres	6	47.4	7	9.03	91.59	464
Choteau	1	38.1	3	5.21	94.09	402
Choteau	2	40.7	4	5.51	92.64	1797
Choteau	3	46	3	5.01	92.54	3885
Choteau	4	40.7	6	8.94	93.41	2739
Choteau	5	37	5	6.98	90.89	3885
Choteau	6	35.89	7	6.08	96.76	2171
Conan	1	40.7	4	6.23	93.3	1049
Conan	2	42.1	3	5.06	94.15	5851
Conan	3	35.5	4	5.89	93.1	4222
Conan	4	35.5	6	7.95	94.29	1413
Conan	5	26.3	5	2.98	95.52	779
Conan	6	39.5	5	6.18	93.04	4347
Fortuna	1	35.5	7	6.77	91.01	3392
Fortuna	2	60.5	3	3.86	91.44	5236
Fortuna	3	47.3	4	5.24	92.62	1997
Fortuna	4	36.8	6	6.24	93.58	1055
Fortuna	5	61.8	3	4.78	97.17	6484
Fortuna	6	43.6	3	3.5	89.73	2503
Hank	1	30.1	4	5.99	95.9	1819
Hank	2	44.7	2	6.1	90.88	4040
Hank	3	42.1	2	5.44	92.88	2523
Hank	4	34.2	3	4.76	92.1	942
Hank	5	36.8	3	4.45	90.68	4679
Hank	6	26.3	4	5.04	95.97	9600
Marquis	1	60.5	3	5.63	93.78	2449
Marquis	2	57.8	6	11.13	92.64	7130
Marquis	3	55.2	4	5.51	94.8	361
Marquis	4	55.2	3	7.1	96.32	383
Marquis	5	46	3	5.54	92.22	2467
Marquis	6	48	4	5.74	85.2	3111
McNeal	1	50	3	5.92	88.27	731
McNeal	2	57.9	3	5.2	91.09	4472
McNeal	3	46.8	3	6	92.98	1946
McNeal	4	40.7	4	7.52	94.84	3574
McNeal	5	42.1	4	6.09	94.22	5449
McNeal	6	46.1	4	4.73	86.1	731
Newana	1	40	3	5.79	96.58	808
Newana	2	50	3	6.35	90.34	2956
Newana	3	48.6	3	5.67	92.39	5107
Newana	4	34.2	5	7.56	94.57	303

Newana	5	44.8	4	5.08	91.77	1803
Newana	6	36.8	3	4.6	93.31	703
Outlook	1	47.3	3	6.48	92.44	754
Outlook	2	44.7	3	5.06	90.47	5557
Outlook	3	57.8	3	6	92.4	1144
Outlook	4	45.1	4	8.1	93.4	690
Outlook	5	44.8	3	6.44	89.7	1734
Outlook	6	47.4	3	5.06	91.68	4573
Reeder	1	50	3	7.3	91.84	1903
Reeder	2	35.5	6	7.07	91.02	3099
Reeder	3	43.4	4	5.48	94.19	1254
Reeder	4	34.7	5	6.66	94.31	152
Reeder	5	44.2	3	4.27	91.67	1665
Reeder	6	34.2	5	4.76	93.58	939
Rushmore	1	40.7	6	7.26	89.57	480
Rushmore	2	56.5	3	5.54	93.55	1107
Rushmore	3	34.2	5	6.68	89.32	2515
Rushmore	4	38.1	5	5.84	95.69	819
Rushmore	5	57.8	2	5.7	93.75	1491
Rushmore	6	53.8	3	6.39	88.34	3824
Scholar	1	42.1	5	9.77	95.35	4334
Scholar	2	47.3	4	6.2	90.67	762
Scholar	3	44.7	6	11.19	91	2417
Scholar	4	39.4	5	7.68	94.28	1060
Scholar	5	ND	ND	ND	90.22	562
Scholar	6	43.6	4	6.27	91.3	3009
Thatcher	1	57.8	6	9.71	90.19	530
Thatcher	2	55.2	3	7.42	93.2	3773
Thatcher	3	57.8	5	7.02	93.03	1160
Thatcher	4	44.7	6	7.08	97.98	2265
Thatcher	5	43.4	5	5.06	91.32	3341
Thatcher	6	55.2	5	6.6	89	3819
Vida	1	38.4	6	8.13	93.63	2424
Vida	2	44.7	5	6.52	90.48	2304
Vida	3	42.1	6	6.59	90.73	846
Vida	4	32.8	6	7.95	91.61	1407
Vida	5	43.4	7	5.98	94.93	2760
Vida	6	38.5	6	8.75	93.99	1043
Excalibur	1	34.2	3	6.49	94.09	319
Excalibur	2	44.7	3	6.1	92.71	761
Excalibur	3	38.1	3	5.71	92.97	1817
Excalibur	4	36.3	4	4.76	95.05	402
Excalibur	5	30.1	5	3.79	94.67	310
Excalibur	6	31.6	3	5.04	90.09	1520
Machete	1	37.3	2	4.08	95.07	1241
Machete	2	31	4	5.06	92.88	625
Machete	3	36.8	3	5.62	90.83	3789
Machete	4	31.5	4	7.95	94.53	966
Machete	5	34.2	3	5.14	89.96	1907
Machete	6	26.3	7	6.18	92.5	2847

APPENDIX F

GREENHOUSE RESISTANCE DATA TRIAL 2

Appendix F. Greenhouse Resistance Data Trial 2: Data is arranged by cultivar and replication number. Data was recorded 12 weeks after planting and consists of biomass measurements, soil moisture, and final nematode populations. Biomass measurements include average tiller height, tiller number, and total biomass from crown up in g. Biomass was not taken for pots where plants had died during trials. Soil moisture was measured by drying 100 g of fresh soil at 70°C for 48 hrs. Final nematode populations are recorded in nematodes/kg dry soil.

GREENHOUSE RESISTANCE DATA TRIAL 2

Cultivar	Rep	Height	Tiller #	Biomass g	Moisture	Final *Neglectus*
Ceres	5	7.62	1	0.05	90.11	438
Ceres	6	50.8	2	2.75	88.63	418
Ceres	2	46.228	3	4.16	92	337
Ceres	3	47.498	3	6.81	94.69	288
Ceres	4	37.084	3	2.59	90.96	227
Ceres	1	46.99	4	6.14	90.67	0
Choteau	3	40.64	4	8.14	91.6	2340
Choteau	1	38.1	3	4.87	93.5	934
Choteau	2	34.29	3	11.39	93.01	849
Choteau	4	41.91	3	4.67	91.04	397
Choteau	6	20.32	1	0.21	90.11	368
Choteau	5	6.604	1	0.04	90.78	239
Conan	1	29.972	2	1.24	89.87	1397
Conan	6	37.592	1	0.15	89.94	1326
Conan	2	20.32	1	0.31	92.79	1220
Conan	4	39.878	2	3	91.76	1064
Conan	5	11.938	1	0.2	91.41	924
Conan	3	37.338	1	0.43	92.1	751
Fortuna	1	41.402	3	2.89	88.27	2101
Fortuna	2	22.352	1	0.38	91.38	1389
Fortuna	3	34.544	3	1.81	94.93	1297
Fortuna	4	43.18	4	2.5	95.54	1105
Fortuna	6	46.736	3	2.12	88.37	964
Fortuna	5	26.67	1	0.46	91.96	361
Hank	3	29.21	3	2.49	87.19	2150
Hank	4	34.544	1	0.61	90.03	1774
Hank	6	39.116	1	0.76	88.78	1703
Hank	1	33.02	2	2.16	91.64	1391
Hank	2	ND	ND	ND	89.9	635
Hank	5	14.732	1	0.28	91.08	543
Marquis	4	42.672	4	4.38	90.46	898
Marquis	1	43.942	7	7.51	94.04	571
Marquis	6	7.112	1	0.05	91.37	461
Marquis	3	50.546	1	1.43	90.58	450
Marquis	2	39.624	3	1.92	89.92	396
Marquis	5	10.16	1	0.12	89.23	0
McNeal	1	36.068	3	4.97	90.02	891
McNeal	3	41.656	2	5.17	95.24	855
McNeal	4	37.592	1	1.98	90.48	390
McNeal	6	45.72	1	1.09	90.1	290
McNeal	2	10.16	1	0.07	90.88	0
McNeal	5	21.082	1	0.2	81.79	0
Newana	5	41.91	3	2.53	91.25	663
Newana	1	41.148	3	3.92	91.68	532
Newana	3	38.1	4	8.65	92.24	475
Newana	4	27.94	2	1.2	92.77	365

Newana	6	47.244	3	2.28	90.44	332
Newana	2	36.322	3	2.27	92.05	0
Outlook	3	47.498	2	5.25	90.05	1894
Outlook	4	43.18	3	7.14	92.46	830
Outlook	6	41.91	1	1.23	83.7	712
Outlook	1	40.64	3	5.15	90.11	639
Outlook	5	42.672	2	2.87	89.84	614
Outlook	2	48.26	3	5.6	92.73	335
Reeder	2	19.558	1	0.15	95.59	985
Reeder	5	10.16	1	0.16	89	934
Reeder	6	39.878	1	1.05	90.09	506
Reeder	1	40.132	3	1.45	88.85	282
Reeder	4	41.656	3	2.18	89.37	268
Reeder	3	41.402	3	5.77	95.86	139
Rushmore	2	27.432	1	0.29	93.32	912
Rushmore	5	19.304	1	0.25	90.72	766
Rushmore	4	8.382	1	0.11	91.08	448
Rushmore	6	17.272	1	0.22	90.13	416
Rushmore	3	28.448	1	0.46	91.23	180
Rushmore	1	48.514	3	1.34	86.41	78
Scholar	3	40.132	4	7.25	89.92	1671
Scholar	1	28.702	1	0.54	93.21	913
Scholar	2	32.258	2	1.07	91.46	815
Scholar	4	47.498	4	7.72	91.61	568
Scholar	5	16.51	1	0.16	90.61	0
Scholar	6	ND	ND	ND	89.51	0
Thatcher	4	50.038	5	4.87	92.98	1676
Thatcher	3	46.482	8	9.2	90.31	1032
Thatcher	1	60.96	4	9.22	94.62	887
Thatcher	2	40.64	3	2.02	91.84	884
Thatcher	5	ND	ND	ND	89.92	845
Thatcher	6	44.45	3	4.02	91.4	474
Vida	3	37.846	4	5.65	89.98	1206
Vida	2	28.956	2	1.03	82.82	955
Vida	1	41.91	8	13.88	92.54	861
Vida	4	37.338	2	3.05	93	800
Vida	6	32.512	1	0.4	87.06	329
Vida	5	9.144	1	0.08	91.67	0
Excalibur	2	34.29	2	2.17	91.5	1455
Excalibur	6	38.1	1	1.1	90.89	717
Excalibur	4	37.084	4	10.99	70.64	467
Excalibur	3	39.37	3	9.72	93.58	281
Excalibur	1	50.546	7	8.09	95.14	248
Excalibur	5	25.4	2	0.49	91.88	0
Machete	4	32.258	4	9.98	92.54	903
Machete	3	30.988	4	7.71	91.96	732
Machete	1	37.338	1	1.41	92.36	610
Machete	5	11.43	1	0.09	91.78	526
Machete	6	37.338	1	0.98	89.26	408
Machete	2	29.21	3	4.38	92.71	155