Associations among Cropping Systems, Root-lesion Nematodes, and Wheat Yield

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Abstract

Wheat in low-precipitation regions of eastern Oregon and Washington is grown mostly as a rainfed winter wheat-summer fallow rotation with wheat planted into cultivated fallow. There are increasing trends for cultivated fallow to be replaced by chemical fallow and for spring cereals to be planted annually without tillage. Most fields are infested by the root-lesion nematodes *Pratylenchus neglectus* and/or *P. thornei*. A replicated multiyear experiment was conducted at the Sherman Experiment Station at Moro, Oregon to compare cropping systems on soil infested by *P. neglectus*. Populations of *P. neglectus* did not differ in cultivated versus chemical fallow. Lowest populations occurred in annual spring barley. Populations became greater with increasing frequency of the host crops mustard, pea, and wheat. Annual winter wheat had the highest *P. neglectus* populations, the lowest capacity to extract soil water, and a lower grain yield compared to winter wheat rotated with summer fallow or other crops. Winter wheat yield was inversely correlated with the population of *P. neglectus*. Measures to monitor and to reduce the populations of *P. neglectus* in Pacific Northwest wheat fields are recommended.

Keywords: barley, mustard, *Pratylenchus neglectus*, root-lesion nematode, spring wheat, summer fallow, water-use-efficiency, winter pea, winter wheat

Introduction

Root-lesion nematodes (*Pratylenchus* spp.) are present in most of the fields in low-precipitation regions of southern Idaho, eastern Oregon, eastern Washington, and northern Montana (Smiley et al. 2004, Strausbaugh et al. 2004, Johnson 2007;). Effects of crop management practices on these nematode populations have not been clearly defined, although much higher populations were detected in annually cropped fields than in winter wheat-summer fallow rotations. Lower populations following fallow and direct associations between *Pratylenchus* spp. population density and frequency of cereal cropping have also been reported in other countries (Gair et al. 1969, Nombela et al. 1998, Riley and Kelly 2002). Barley is generally considered a poorer host than wheat (Taylor et al. 2000, Smiley et al. 2004, Thompson et al. 2008, Vanstone et al. 2008). Compared to wheat in a lesion nematode-infested soil in Australia, barley was more efficient at extracting soil water and barley yields were more responsive to stored soil moisture in a year with limited in-crop rainfall (Thompson et al. 1995).

Only two species of root-lesion nematodes are prevalent in Pacific Northwest (PNW) dryland fields and both species (*Pratylenchus neglectus* and *P. thornei*) cause substantial constraints to grain yields in rainfed cereals worldwide (Castillo and Vovlas 2007, Smiley and Nicol 2009). Both species have reduced yields of annually cropped spring wheat by as much as 70 percent in the PNW (Smiley et al. 2005a,b) but these studies did not compare effects of various crop management systems on these species. Smiley et al. (2004) reported presumptive evidence that yield of winter wheat was reduced by *P. neglectus* but the effects of potential variations in the amount of stored soil water in the rotations were not examined in that study.

Ninety percent of the winter wheat acreage in eastern Oregon and Washington is managed as a winter wheat-summer fallow rotation. Most of the summer fallow acreage is managed as cultivated dust mulch but chemical fallow is becoming increasingly popular. Three-year rotations of winter wheat, a spring crop, and chemical fallow also are of interest but have not yet been widely adopted because they are often less profitable even though they have less year-to-year economic risk compared to the winter wheat-summer fallow systems. Direct-seeded fields planted annually to spring crops are also becoming increasingly practiced in the low-precipitation region. However, fields planted annually to no-till spring crops are planted mostly to wheat or barley because these small grain crops are generally more profitable than rotations that include broadleaf crops such as yellow mustard or canola. While increasingly important, annual no-till spring cropping is not yet widespread because it is less profitable than the winter wheat-summer fallow rotation (Juergens et al. 2004; Schillinger et al. 2006a,b; Machado et al. 2007; Bewick et al. 2008). In continuous annual cropping systems near Pendleton, Oregon, spring barley produced 34 percent and 45 percent greater yields than spring wheat in cultivated and direct-drill systems, respectively, as well as 25 percent and 5 percent greater yields than winter wheat-summer fallow rotations with cultivated and chemical fallow, respectively (Machado et al. 2007).

A replicated long-term experiment was established during 2003 to examine multidisciplinary aspects of eight cropping systems at a low-precipitation site known to be infested with *P. neglectus*. This paper is an abbreviated version of a technical paper (Smiley and Machado 2009) in which we reported associations between cropping systems, nematode populations, grain yields, and water extraction over the first 5 years of the long-term experiment at Moro.

Materials and Methods

The experiment was performed at the Columbia Basin Agricultural Research Center at Moro, in Sherman County, Oregon. The site averaged 11 inches annual precipitation over the past 10 years and the soil is a moderately deep (mostly more than 40 inches) Walla Walla silt loam.

Field operations

Management of the experimental area was described in a previous report (Machado et al. 2008). Briefly, a uniform crop of spring wheat was planted over the intended experimental area during 2003. The experimental area was mapped into 42 plots (each 48 by 350 ft) arranged as 3 replicated blocks where each contained 14 plots representing 8 crop treatments. Numbers of plots (14) in each replicate were greater than the number of crop treatments (8) because each phase of each multiyear crop treatment was present in all years to allow treatment data to be collected for each year. The eight treatments included annual winter wheat; annual spring wheat; annual spring barley; winter wheat-summer fallow rotation with either cultivated or chemical fallow; a 2-year rotation of winter wheat and winter pea; a 3-year rotation of winter wheat, spring barley, and chemical fallow; and flexible cropping (flex crop) to allow annual flexibility in selecting the crop species produced. Flex-cropping decisions were made by an advisory committee made up of the project leader and producers, and were based on market prices, soil moisture available before planting, and occurrences of weeds and diseases. Two flex-crop treatments included winter wheat, chemical fallow, and spring-planted crops of barley, camelina, pea, mustard, and wheat.

Seven of the eight crop treatments were managed without tillage (no-till) using direct-drill technology. All direct-drill treatments were planted using a Fabro disk-type drill with 12-inch row spacing. A blend of urea and ammonium sulfate was banded 1 inch below the seed of all direct-drill small grains crops at application rates based on industry standards and results of annual soil tests by commercial laboratories. Herbicides were applied to all crop treatments during the growing season in accordance with weed populations and industry standards.

Direct-drill spring wheat and spring barley occurred in the annual crop sequences and in the 3-year and flex-crop rotations (Table 1). These crops were planted in April. Cultivars of spring wheat included 'Zak' in 2004 and 2005, and 'Louise' from 2006 to 2008. The spring barley cultivar was 'Camas' from 2004 to 2007 and 'Haxby' during 2008. Direct-drill winter pea occurred in the 2-year rotation and was planted during October or November. Cultivars were Line PS9430706 in 2004 and 'Spector' from 2005 to 2008. Granular Nitragin® inoculant was applied with the seed and starter fertilizer (10 lb N/acre) was banded below the seed at a depth of 3 inches. Direct-drill spring camelina (cv. 'Calena'), spring mustard (cv. 'Tilney') and spring pea (cv. 'Universal') were planted into flex-crop treatments during April.

Direct-drill winter wheat occurred in the annual and wheat-fallow sequences, the 2- and 3-year rotations, and in flex-crop rotation no. 2 (Table 1). Plots to be planted to direct-drill winter wheat were sprayed once in late September or early October with glyphosate to control summer weeds. Glyphosate was also applied to control weeds two to three more times during the spring and summer of the fallow phase of the direct-seeded biennial winter wheat treatment managed with chemical fallow. Direct-drill winter wheat was planted in October or November. Cultivars were 'Tubbs' in 2004, 'Stephens' in 2005, and 'ORCF-101' from 2006 to 2008.

Compared to direct-drill treatments, management of the winter wheat-summer fallow treatment differed considerably when planted into cultivated fallow. After the wheat crop was harvested the plots were not cultivated until mid-April of the following year. Glyphosate was applied as needed in the fall and spring. In April, primary tillage was conducted to a depth of 6 inches using a John Deere 1600 cultivator fitted with chisel plow turning points, followed by sweep cultivation to a depth of 5 inches using the JD 1600 equipped with 12-inch-wide sweeps. Plots were rod-weeded at a depth of 3 to 4 inches whenever necessary to maintain weed control and the dust mulch fallow. Plots were generally rod-weeded two or three times between May and August. In accordance with industry standards and based on soil sampling, anhydrous ammonia and gypsum were incorporated into fallow treatments during September to meet soil fertility requirements. Winter wheat was planted in mid-September using a John Deere 7616 HZ drill with 16-inch row spacing. Cultivars were the same as for direct-drill winter wheat.

All crops were harvested as a strip following the centerline of each 48-ft-wide plot using a commercial combine with an 18-ft header. Grain yield was measured using a weigh wagon to determine yield per plot.

Soil water

Measurements of soil water content were conducted throughout the 2006 and 2007 growing seasons using a PR2 probe (Delta-T Devices Ltd., Cambridge, England). Access tubes were inserted by extracting a soil core using a tractor-mounted Giddings Hydraulic Soil Sampler. The PR2 probe senses soil moisture content (percent volume) at 4-, 8-, 16-, 24-, and 40-inch depths by responding to dielectric soil properties. Readings were made on two access tubes located 45 ft apart in each plot. Three measurements were recorded at each reading, with the probe rotated to a different direction for each measurement.

Routine soil sampling and nematode extraction

Soil was collected each year to assess *P. neglectus* populations in individual treatments during mid-March to mid-April, when soil was moist shortly before or after spring crops were planted. Samples consisted of 20 cores (1 inch diameter) composited for each of the 42 plots. Samples were collected to 6-inch depth during 2004 and 2005. Sampling was changed to 12-inch depth during 2006 to 2008 after we learned that deeper sampling was necessary to adequately quantify populations of lesion nematodes in wheat-fallow rotations (Smiley et al. 2008). Samples were transported to Western Laboratories in Parma, Idaho for nematode extraction and quantification.

Profile depth sampling

Soil cores were collected from all plots during 2008 using the Giddings Hydraulic Soil Sampler with a 2-inch-diameter, 5-ft-long slotted soil tube and heavy-duty bit. Soil cores were collected to 4-ft depth and separated into 12-inch intervals. A pair of soil cores was collected 3 ft apart at each sampling location to ensure sufficient soil was collected for each depth interval and to minimize the effect of the inherent spatial variability of the nematodes. Corresponding depth intervals from the pair of cores taken from each sampling location were composited into individual samples. Nematodes in each soil depth interval were extracted and quantified.

Statistical analysis

Nematode data were transformed using $\ln(x + 1)$ to normalize population estimates prior to statistical analysis. Results were analyzed using one-way analysis of variance (ANOVA) and the logarithmic means were then back transformed into real numbers for presentation. Grain yields were also analyzed by ANOVA. Long-term effects of rotations were evaluated by grouping grain yield and nematode data over years. Subsets of the data were also evaluated. Examples of subsets included soil-sampling depth intervals grouped across crop treatments, or crop treatments grouped according to the crop or field management treatment immediately preceding a soil sampling date, or the two crops or management treatments before samples were collected. Associations of grain yields and nematode populations, and results of hand sampling versus mechanized core sampling procedures to assess nematode populations were evaluated by regression analysis.

Results

The only plant-parasitic nematode considered capable of affecting plant health in this experiment was *Pratylenchus neglectus*. Numbers of this species were vastly greater than for any other plant-parasitic species. Populations averaged over the 5-year sampling period revealed that highest average numbers corresponded in general with the frequency of host crops (wheat, pea, and mustard) in the crop sequence. The highest average (Table 1) occurred in annual winter wheat and annual spring wheat, the 2-year wheat-pea rotation, the winter wheat-summer fallow sequences in which wheat was produced in 3 of 5 years, and in the flex-crop rotation no. 1, in which spring wheat and spring mustard were produced in 3 of 5 years. The lowest numbers occurred in annual spring barley, the winter wheat-summer fallow sequences in which wheat was produced in only 2 of 5 years, and in the 3-year rotations in which wheat was produced in only 1 or 2 of 5 years.

Populations of *P. neglectus* were also analyzed to determine effects of the preceding crop or fallow treatment from 2005 to 2008. Populations after spring barley and fallow were about half the populations following wheat or pea (Table 2). The influence of spring mustard on populations of *P. neglectus* was intermediate between wheat and barley. Compared to annual winter wheat, populations of *P. neglectus* diminished when winter wheat was rotated with either chemical or cultivated fallow— the type of fallow had no effect on nematode populations.

Results of deep core data collected from the 42 plots during 2008 revealed low numbers (less than 140/lb of soil) of *P. neglectus* were detected throughout the profile of annual spring barley (Fig. 1). Populations were higher in annual spring wheat and annual winter wheat but the peak population density was about 12 inches deeper in the profile for winter wheat than for spring wheat. Populations of *P. neglectus* were particularly high following sequences of spring mustard and spring wheat, and of winter pea and winter wheat.

Populations of *P. neglectus* also were analyzed by grouping the 12-inch depth intervals across crop sequences and analyzing the data. Significantly higher populations ($LSD_{0.05}$ = 370/lb of soil) occurred in the first and second foot intervals (1,600/lb and 2,000/lb, respectively) than in the third (715/lb) and fourth foot (186/lb) intervals. Results of data collected in the surface foot of soil were comparable ($R^2 = 0.64$, $P < 0.0001$) for three pairs of deep cores collected by hydraulic sampler and 20 cores collected by manual sampling.

When data were grouped over the entire 4-ft-profile depth and also across each phase of each crop treatment, the average number of *P. neglectus* was significantly higher in flex-crop rotation no. 1 (1,672/lb of soil), the 2-year wheat/pea rotation (1,590/lb) and winter wheat-chemical fallow (884/lb) compared to the annual spring barley (79/lb) and 3-year rotation (317/lb).

As expected, grain yields were affected by precipitation. Total precipitation for crop years 2003, 2004, 2005, 2006, 2007 and 2008 was 9.3, 11.9, 7.9, 16.9, 11.1, and 8.7 inches, respecttively, which corresponded with generally lower yields during 2005 and 2008. Grain yield also differed significantly among treatments during 2004 (Table 3) but the result was considered to have no importance with respect to crop rotation effects being investigated because 2004 was

Table 1. Crop management treatments and number of lesion nematodes in the top foot of soil during 5 years of 8 cropping systems at Moro, Oregon.

	Harvested crop or field management[a]					*P. neglectus*/lb of soil[b]					
Crop sequence	*2004*	*2005*	*2006*	*2007*	*2008*	*2004*	*2005*	*2006*	*2007*	*2008*	*mean*
Annual spring barley	SB	SB	SB	SB	SB	135 a	1,095 a	214 bcd	314 cd	188 e	285 b
Annual spring wheat	SW	SW	SW	SW	SW	112 a	1,287 a	513 abc	1,644 ab	3,928 ab	864 ab
Annual winter wheat	WW	WW	WW	WW	WW	260 a	1,271 a	1,420 a	2,029 a	2,671 ab	1,206 a
Winter wheat-chem. fallow	WW	ChF	WW	ChF	WW	1,727 a	408 a	492 abc	1,333 ab	2,139 abc	998 ab
Winter wheat-chem. fallow	ChF	WW	ChF	WW	ChF	192 a	188 a	98 d	333 cd	1,665 abcd	288 b
Winter wheat-cult. fallow	WW	CuF	WW	CuF	WW	622 a	2,236 a	426 abc	1,479 ab	1,489 abcd	1,055 a
Winter wheat-cult. fallow	CuF	WW	CuF	WW	CuF	275 a	391 a	447 abc	311 cd	1,109 abcd	440 ab
2-year rotation	WW	WP	WW	WP	WW	381 a	674 a	540 abc	2,455 a	5,024 a	1,113 a
2-year rotation	WP	WW	WP	WW	WP	152 a	616 a	769 ab	1,031 abc	3,330 ab	757 ab
3-year rotation[c]	WW	SB	ChF	WW	SB	270 a	857 a	402 abcd	169 d	423 de	366 ab
3-year rotation	SB	ChF	WW	SB	ChF	322 a	160 a	155 cd	982 abc	857 bcde	368 ab
3-year rotation	ChF	WW	SB	ChF	WW	530 a	851 a	742 ab	758 abc	545 cde	673 ab
Flex-crop rotation no. 1[d]	SB	SW	SM	SW	SP	349 a	1,055 a	305 bcd	836 abc	3,504 ab	800 ab
Flex-crop rotation no. 2	SW	SB	ChF	WW	SC	208 a	674 a	701 ab	500 bcd	1,274 abcd	575 ab

[a] ChF = chemical fallow, CuF = cultivated fallow, SB = spring barley, SC = spring camelina, SM = spring mustard, SP = spring pea, SW = spring wheat, WP = winter pea, WW = winter wheat. The experimental area was planted uniformly to spring wheat in 2003. All except the winter wheat-cultivated fallow treatment were direct seeded, e.g., no-till.

[b] Means followed by the same letter within a column are not significantly different at $P = 0.05$. All crops and fallow treatments were sampled shortly before or after spring crops were planted during March. Therefore, crops planted during the autumn were "in-crop" for 5 months prior to sampling.

[c] Winter wheat plots in the 3-year rotation were very dry and compact in 2007. Low numbers of *P. neglectus* in those three plots may be biased by a shallower sampling depth during 2007.

[d] Flex crop = rotational sequences were determined annually based on available stored water, crop prices, weeds, and diseases.

Table 2. Average number of lesion nematodes in the top foot of soil during the spring following harvest of a specific crop or following a fallow management treatment over the 4-year interval 2005 to 2008 in 8 crop sequences at Moro, Oregon.

Previous crop or management [a]	*P. neglectus*/ lb of soil [b]
Spring wheat (21)	1,174 a
Winter pea (12)	1,145 ab
Winter wheat (63)	1,035 ab
Spring mustard (3)	836 ab
Cultivated fallow (12)	527 ab
Chemical fallow (30)	441 b
Spring barley (27)	440 b

[a] Data are the means of the total number of times each crop or fallow management sequence occurred (shown in parenthesis) over the 4-year interval in 8 cropping sequences.

[b] Means followed by the same letter are not significantly different.

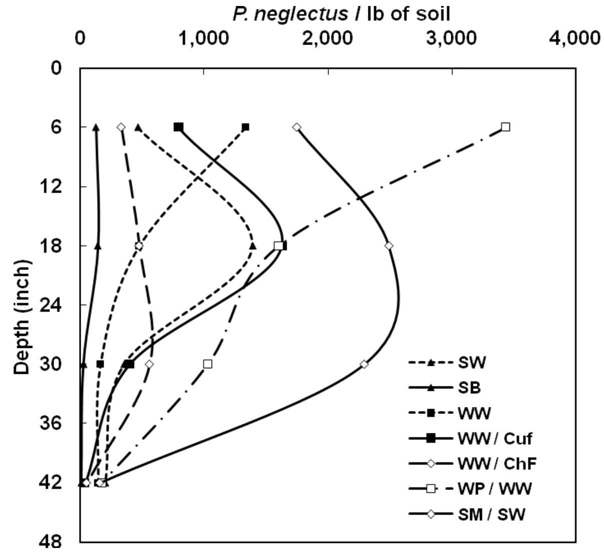

Figure 1. Distribution of lesion nematodes at 1-ft depth intervals to a depth of 4 ft in 7 crop sequences in the long-term experiment at Moro, Oregon during April 2008: direct-drill annual spring wheat (SW), spring barley (SB), or winter wheat (WW), direct-drill spring wheat after spring mustard (SM/SW), winter wheat alternated with either cultivated fallow (WW/CuF) or chemical fallow (WW/ChF), and winter wheat rotated with winter pea (WP/WW).

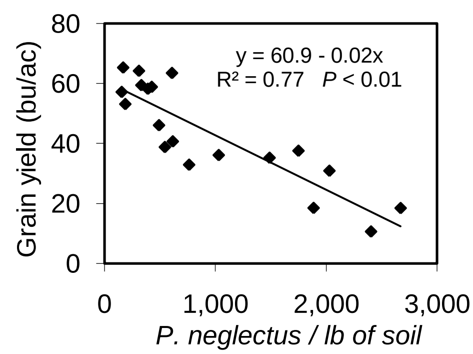

Figure 2. Relationship between numbers of lesion nematodes and grain yields for winter wheat in 5 crop rotations over 4 crop years, 2005-2008; treatments include annual winter wheat, winter wheat rotated with either cultivated or chemical fallow, 2-year winter wheat-winter pea rotation, and 3-year winter wheat-spring barley-chemical fallow rotation.

Table 3. Grain yield for wheat and barley crops produced over 4 crop years in 8 crop sequences at Moro, Oregon. All plots were direct seeded (no-till) except winter wheat in the cultivated fallow treatment.

Crop and crop sequence[a]	2004[b]	2005	2006	2007	2008	4-yr mean
Spring barley				*grain yield (lb/acre)*		
Annual spring barley	3,420 a	731 c	4,002 a	2,475 d	1,409 c	2,155 b
3-year rotation	2,557 c	803 c	3,651 a	2,255 de	587 e	1,824 bc
Flex-crop rotations[c]	2,633 c	848 bc				-
Spring wheat						
Annual spring wheat	2,983 c	765 c	2,856 bc	2,423 e	1,013 d	1,764 bc
Flex-crop rotations[c]	2,799 c	975 c		2,195 f		-
Winter wheat						
Annual winter wheat	3,853 ab	801 c	1,394 d	2,329 ef	1,390 c	1,479 c
Winter wheat-chemical fallow	3,698 ab	4,007 ab	3,475 b	4,482 b	2,832 ab	3,699 a
Winter wheat-cultivated fallow	3,640 b	4,391 a	4,439 a	4,842 ab	2,656 b	4,083 a
2-year rotation	3,674 ab	3,068 ab	2,481 c	2,723 de	897 d	2,291 b
3-year rotation	3,792 ab	4,788 a	4,311 a	4,925 a	2,925 a	4,238 a
Flex-crop rotation no. 2[c]				3,898 c		-

[a] Grain yields in eight crop sequences.
[b] Means followed by the same letter within a column are not significantly different at $P = 0.05$. The 4-year mean is of grain yields for crops harvested during the last 4 years, 2005-2008.
[c] Flex crop = rotational sequences were determined annually based on available stored water, crop prices, weeds, and diseases.

the first rotational sequence following a uniform crop of spring wheat during 2003. In 2005 spring crops fared poorly due to drought. Highest yields were produced by winter wheat in the 2- and 3-year rotations and in the winter wheat-cultivated fallow treatment. During 2006 spring barley in the annual crop sequence and in the 3-year rotation produced yields statistically equivalent to winter wheat-cultivated fallow and winter wheat in the 3-year rotation. The lowest yields in 2006 were for annual winter wheat and winter wheat in the 2-year rotation. In 2007 the highest yields were from winter wheat in the 3-year rotation and in the winter wheat-cultivated fallow. The lowest wheat yield during 2007 was the spring wheat in flex crop no. 1, following a sequence of spring wheat and spring mustard. During 2008, annual spring barley produced more grain than annual spring wheat but was equal to the amount of grain produced in the annual winter wheat treatment. The highest producing winter wheat occurred in the winter wheat-summer fallow sequences and the 3-year rotation.

Mean grain yields over the 3 crop years 2005 to 2007 (Table 3) indicated that the highest yields were achieved for winter wheat in the 3-year rotation and in the winter wheat-cultivated fallow. These highest-yielding treatments were followed, in order of decreasing yield, by winter wheat-chemical fallow, winter wheat in the 2-year rotation, annual spring barley, spring barley in the 3-year rotation, annual spring wheat, and annual winter wheat. The yields for winter wheat in five crop sequences (all except the flex crops) from 2005 to 2008 were strongly and negatively correlated with populations of *P. neglectus* in the upper foot of soil during the spring (Fig. 2).

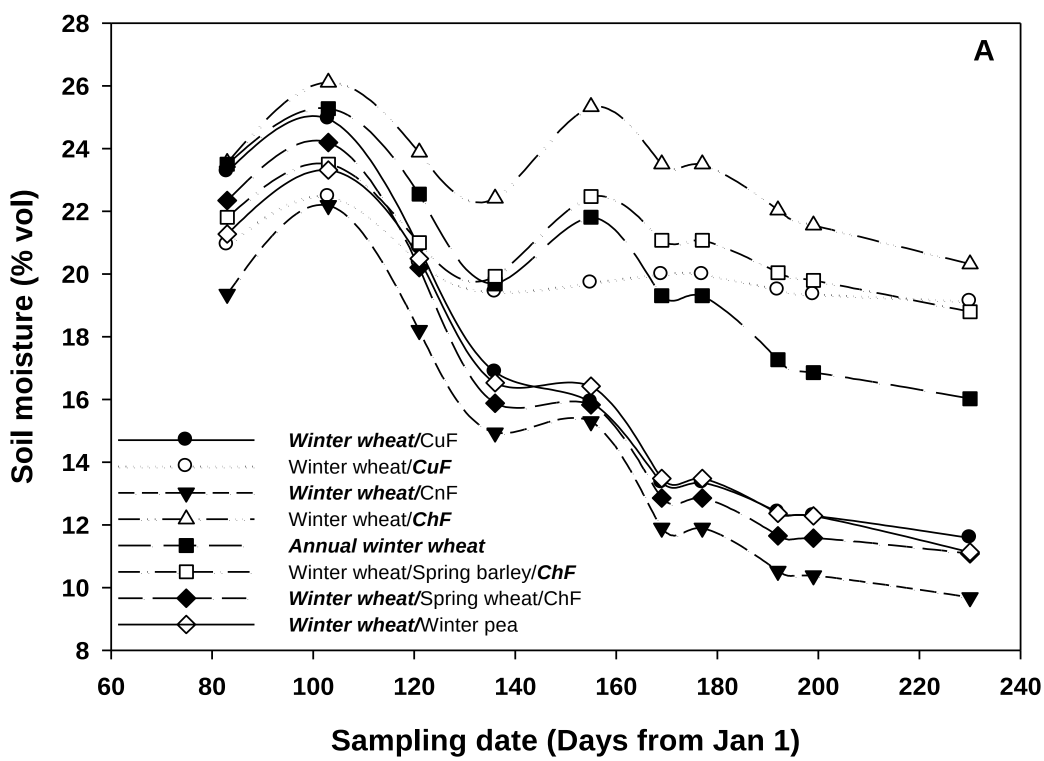

Figure 3. Mean soil water content under all rotations in the 0- to 4-ft depth profile at Moro from March to September during 2006. Data are for the crop or treatment shown in boldface and italics of a crop or management sequence; CuF = cultivated fallow and ChF = chemical fallow.

Soil water content was monitored in the profiles of each crop sequence during the spring and summer of 2006 and 2007. Three soil moisture patterns were evident during 2006 (Fig. 3). Greater moisture was present at the end of the growing season for the three fallow treatments compared to all winter wheat treatments except annual winter wheat, which was intermediate between the fallow treatments and winter wheat in other crop sequences. Compared to winter wheat in other crop sequences, the annual winter wheat extracted a lower amount of water from soil and had the greatest population of *P. neglectus* (Table 1) and lowest grain yield (Table 3). The relationships between soil moisture extraction, nematode populations, and relative grain yields were similar although slightly less pronounced during 2007.

Discussion

Population densities and the vertical distribution of the root-lesion nematode, *Pratylenchus neglectus*, in soil profiles were strongly influenced by cropping systems. The lowest populations were detected when barley was planted annually and the highest populations occurred when winter wheat was planted annually or rotated with winter pea. These results are in agreement with the recognition of barley as generally more tolerant and more resistant than wheat to *P. neglectus* and *P. thornei* (Taylor et al. 2000; Smiley et al. 2004, 2008; Thompson et al. 2008; Vanstone et al. 2008). Our findings are also in agreement with previous observations that *Pratylenchus* species become more numerous as host-crop frequency is increased (Gair et al. 1969, Riley and Kelly 2002). Although Strausbaugh et al. (2004) detected fewer lesion nematodes in chemical than cultivated fallow, no differences between fallow type were detected in this study or by Brmež et al. (2006) or Smiley et al. (2004). Likewise, observations near Heppner indicated that the *P. neglectus* population was comparable following mustard and wheat (Smiley et al. 2008). However, it was unexpected that *P. neglectus* populations in the winter wheat/winter pea rotation would be comparable to those in rotations containing known "good" host species (Thompson et al. 2008, Vanstone et al. 2008) every year, as in annual winter wheat and annual spring wheat. Field pea was resistant to *P. neglectus* in Australia (Vanstone et al. 2008) but was associated with high populations of *Pratylenchus* species in the PNW (Riga et al. 2008). The role of pea in developing high populations of lesion nematodes needs to be examined in greater detail.

Winter wheat is typically planted into cultivated fallow during September and into chemical fallow during October. Seedlings become established and reach the second through fourth leaf stage before onset of semi-dormancy during winter. Active seedling growth resumes during early spring at a time when spring cereals are being planted. Soil sampling to assess nematode populations in this experiment was performed as spring cereals were being planted. Populations of nematodes detected in winter wheat during the spring, 6 months after the wheat was planted, were numerically higher in the fallow phase than the "in-crop" phase in 4 out of 10 comparisons and were significantly lower than the "in-crop" phase in only 1 of 10 comparisons. An identical phenomenon, with fewer comparisons, also occurred in multiyear samplings of wheat and fallow near Heppner (Smiley et al. 2008). It is common for most lesion nematodes to inhabit roots during periods of active root growth, to move into and out of roots throughout active root growth, and to become more prevalent in soil during periods when soil is moist but without the presence of a living host (Castillo and Vovlas 2007).

Smiley et al. (2004) reported that lesion nematode populations inside cereal roots were lowest during the spring (May) and increased to a maximum as mature roots died before harvest in July. Populations detected in soil were lowest during June and July and highest during October, after roots had died and new tissue was not yet available for recolonization. Smiley et al. (2004) also observed that *Pratylenchus* spp. became active colonists of volunteer cereals and grass weeds (mostly downy brome [cheatgrass]) that were stimulated into seed germination and seedling growth following the onset of rain during the autumn. They found lesion nematode populations in roots of volunteers and grass weeds during October to be comparable to populations in planted spring and winter cereals the following May. *Pratylenchus* species are hosted by a large and diverse number of plant species (Castillo and Vovlas 2007, Vanstone et al. 2008). As with most commercial winter wheat-summer fallow practices, winter wheat stubble in this experiment was not treated with herbicide or tillage from early autumn (October) until the following spring (March-April). An interval of zero to several weeks separated the spring weed management program and collection of samples to assess nematode populations in all treatments, including the fallow. Although populations of lesion nematodes were not monitored in the volunteer cereals and weed grasses in this experiment, there was ample opportunity for multiplication of nematodes through the 10-month winter wheat growth cycle and also, when temperatures permitted, for as many as 7 months of the 14-month “fallow” cycle. We conclude that management of lesion nematodes in the winter wheat-summer fallow region must include eliminating the potential for them to multiply during the fallow period. In soils infested with these nematodes, living plants must not be allowed to persist during the intervals between planted crops.

The vertical distribution of lesion nematodes is highly variable and influenced by such factors as root distribution and soil moisture, temperature, texture, and depth. Sampling to 4- to 6-inch depths is sometimes considered adequate in shallow soils but peak populations are known to occur at considerably greater depth in some deep soil profiles. Smiley et al. (2008) reported that sampling to 12-inch depth always detected more than 50 percent of the lesion nematode population in profiles of silt loams in Oregon. Also, sampling to 18-inch depth detected more than 75 percent of the population in at least 75 percent of samples evaluated. Deep-core samplings per-formed during this experiment revealed that 12-inch-deep samplings enabled us to detect an average of 36 percent (range of 16 to 63 percent) of the total lesion nematode populations in the crop rotations examined. The mean detection level was 81 percent (range of 74 to 87 percent) when samples were collected to a depth of 2 ft. Although a sampling depth of 12 inches was minimally acceptable for comparing lesion nematode numbers among crop management treatments in these deep silt loam soils, a sampling depth of 18 inches was much more informative. Distinguishing nematode populations at a high level of precision, as needed to accurately deter-mine effects of cropping systems, will continue to require laborious and expensive sampling to at least 2-feet depths and segmenting the soil cores into 6- to 12-inch intervals prior to extracting the plant-parasitic nematodes.

Pratylenchus neglectus and *P. thornei* were only recently reported as being common and in high numbers in many fields of the low-precipitation regions of the PNW (Smiley et al. 2004, Strausbaugh et al. 2004), and potential impacts of these species on yield of spring wheat were discussed (Smiley et al. 2005a,b). Presumptive evidence that lesion nematodes also restricted yields of winter wheat was reported (Smiley et al. 2004) but that observation did not provide evidence that the wheat yield was not also influenced by availability of stored soil water, even though the experiment was performed on a shallow silt loam soil between Pilot Rock and Pendleton, where all stored water would be expected to be extracted by each crop each year. In this paper we report that high populations of lesion nematode were associated with reduced yields of winter wheat, and that the greatest yield reduction occurred in the rotation where the least amount of water was extracted during the growing season. Thompson et al. (1995, 2008) previously reported that roots affected by lesion nematodes were less capable of extracting water and plant nutrients, and became prematurely moisture stressed, particularly towards the end of the growing season or in dry years. Wheat in the PNW often receives little effective rainfall late in the growing season and generally depletes stored water in the soil profile before plant maturity. It is now clear that root dysfunction caused by lesion nematodes reduces the capacity of plants to extract deeply stored water late in the growing season. Cropping systems that lead to the highest lesion nematode populations become least efficient for extracting deeply stored soil water.

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