The Effects of Pathogen Numbers and Tillage on Root Disease Severity, Root Length, and Seed Yields in Green Peas

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ABSTRACT

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A 2-yr field study was conducted to determine the effects of soil compaction and inoculum levels of *Fusarium solani* f. sp. *pisi* on pea (*Pisum sativum*) root length, disease severity, plant biomass, and dry seed yields. Soil inoculum levels of *F. s.* f. sp. *pisi* were significantly reduced by fumigation with methyl bromide at the 0–20 cm depth but were not reduced below 20 cm. Use of a paraplow treatment to reduce compaction increased root density over that obtained with the conventional moldboard plow treatment. The combination of fumigation and paraplow tillage decreased root disease severity and increased root length, biomass, and dry seed yields.

Additional keywords: Fusarium root rot

Green peas (*Pisum sativum* L.) are primarily grown in rotation with fall-planted cereals where rainfall is sufficient to support annual cropping in the Blue Mountain area of northeastern Oregon and southeastern Washington. Peas are an important rotation crop in this system because of their short growing season and adaptability and because of the low input required. An important yield constraint is root disease caused primarily by *Fusarium solani* (Mart.) Sacc. f. sp. *pisi* (Jones) Snyd. & Hans. (6,7).

Early, vigorous pea growth is essential for an economical yield because soilborne diseases are directly influenced by plant vigor (3,4). Soil compaction, inadequate fertility, deficient or excessive soil moisture, and high air temperatures increase the severity of Fusarium root rot (7). In some field sites, tractor wheels and tillage implements create compacted soil layers that are not readily penetrated by infected pea roots (1). Infected roots are reduced in volume when severely rotted and unable to grow into sources of water and nutrients necessary for optimum yields (1).

This study was conducted to determine the effects of compaction and the depth distribution and inoculum levels of *F. s.* f. sp. *pisi* on pea root length, disease severity, biomass, and dry seed yields under field conditions.

MATERIALS AND METHODS

The effects of pathogen density and soil compaction on pea root disease severity were studied at two field sites in Walla Walla County, southeastern Washington, in 1986 and 1987 (Table 1). Soil pH had decreased at both sites from 6.9 to 5.0 as a result of long-term use of anhydrous ammonia, and abiotic properties were layered as a result of long-term tillage practices (6). This is an area where a pea-wheat rotation was followed for 20–30 yr and pea root diseases are prevalent. The experimental design was a split-split plot in strips, with tillage as whole plots and fumigation as subplots. There were four treatments with six replications per treatment at both sites and years. Each year, the study was conducted in a pea rotation field following wheat. Wheat stubble from the preceding winter wheat harvest was shredded with a rotary mower in late July.

Treatments consisted of tillage with either a four-legged paraplow (Howard Rotavator Company Ltd., Mendham Lane, Harleston, Norfolk IP020 9DP, United Kingdom) or a pull-type moldboard plow with six 46-cm bottoms (John Deere model 3600). The paraplow, developed from a slant-legged implement and originally intended for conventional drainage and subsoiling work, has a working depth of 25–35 cm. The legs are spaced 51 cm apart and are designed to minimize disruption of the soil surface while the soil in front of each leg is lifted and cracked to create a looser, less compacted soil. Paraplow tillage was used to reduce or eliminate the tillage pan created by the moldboard plow at a depth of 20–35 cm (1). Treatments were applied in either August or September. Glyphosate was applied in March at 1.122 kg/ha in 189.3 L of water for weed control. Both sites were cultivated (field cultivator model 1400-D12, Caulkins Manufacturing Co., Spokane, WA) twice to create a suitable seedbed.

A hand-held recording penetrometer with a 30-cone and base area of 1.3 cm^2 was used, as suggested in ASAE Stan-

Table 1. Soil characteristics and precipitation at research field sites

Field location	Soil identification	Soil depth (m)	Slope (%)	Annual precipitation (mm)	Elevation (m)
Ferrel	Walla Walla silt loam (coarse-silty, mixed, mesic, Typic Haploxerolls)	>3	1–2	400	340
Meiners	Palouse silt loam (fine-silty, mixed, mesic, Pachic Ultic Haploxerolls)	2	9–13	560	640

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dard S313.2 (2), to record compaction at various soil depths. Five penetrations were made for each plot, with cone index recordings made at 3.5-cm intervals to a 76-cm depth. Water status in the soil profile was monitored biweekly with a neutron moisture meter at soil depths of 15, 45, 75, and 105 cm.

Designated test plots were fumigated with a Hendrix and Dail (Greenville, NC) solid tarp fumigator to reduce inoculum levels of *F. s.* f. sp. *pisi*. A mixture of 97% methyl bromide and 3% chloropicrin was applied at 448.3 kg/ha and sealed with 6-mil clear plastic. Each of two fumigated strips was 30.5 m long × 3.0 m wide, with three moldboard and three paraplow replications per strip. The fumigation strips were perpendicular to the tillage treatments. One week after fumigation, a 10-row grain drill on 17.8-cm centers was used to plant all plots with pea cultivar Dark Skin Perfection at 252 kg/ha.

Prior to planting, 10 composite samples per subplot treatment, each consisting of three soil cores, were taken using a 4-cm-diameter soil probe to a depth of 40 cm in 10-cm increments that were kept separate. The resultant soil samples were air-dried in paper bags and assayed for levels of *F. s.* f. sp. *pisi*, using the dilution plate procedure and modified Nash and Snyder's *Fusarium*-selective agar medium (10).

Disease severity data were taken when 50% of the plants had immature pods in the first bloom node. Twenty-five plants per plot were dug, and rhizosphere soil was removed by shaking tightly adhering soil into a paper bag. Harvested plants were placed in plastic bags, cooled over ice, and transported to the laboratory. Each plant was rated on a 0–5 disease severity scale, where 0 = healthy and 5 = completely rotted root system. Fresh weights of plant tops also were recorded to the nearest 0.1 g. Twelve root samples per plot were excavated directly over a crop row to determine root length. A 7.6-cm-diameter soil probe in a hydraulic soil-coring machine (Giddings Machine Co., Fort Collins, CO) was inserted to a depth of 30 cm. Each core was subdivided into 7.6-cm increments, cooled, transported to the laboratory, and stored at 2 C until assayed. Soil cores were placed into a root elutriator (Gillison's Variety Fabrication, Inc., Benzonia, MI), and root samples were collected after a 3-min wash (12). The samples were stained with 10% Congo red dye and the root length of each sample was measured, using the root-line intercept procedure of Ward et al (13). A grid of 36 lines spaced 1 cm apart was printed on Mylar film and sealed on the bottom of a 30 × 38 cm shallow pan. A root sample was placed in the pan in sufficient water to allow random dispersement of the roots. Ten lines were selected for counting roots. The number of intercepts between live stained roots and the 10 reference lines was counted manually. The total number of root-line intercepts per sample was multiplied by the factor 0.0091 to convert the values to root length in centimeters per cubic centimeter of soil (13).

At seed maturity, plots were windrowed and harvested with a self-propelled plot combine. Seed was cleaned and weighed to the nearest 0.1 g. All data were analyzed with the MSTAT program (Integrated Microcomputer Program, Crop & Soil Sciences Department, Michigan State University, East Lansing) for a split-split plot design. Orthogonal comparisons also were analyzed according to MSTAT. Data from each year were analyzed separately.

RESULTS

Fumigation significantly reduced the soil populations of *F. s.* f. sp. *pisi* in the 0–40 cm depth at the Ferrel site but only to the 10–20 cm depth at the Meiners site (Table 2). In both years, fumigation was more effective in reducing *Fusarium* populations at the Ferrel site than at the Meiners site. There were no significant differences in rhizosphere soil populations of *F. s.* f. sp. *pisi* from plants at full bloom when grown in control or fumigated soil in either year.

Root length was determined for each treatment at four depth increments at each site in 1986. By an orthogonal comparison analysis, there was a significant interaction ($P = 0.05$) between soil depth and tillage (comparing moldboard and paraplow treatments) on root length and in shallow rooting vs. deep rooting at the Ferrel site (Table 3). Fumigation alone at the Ferrel site had no effect on root length but had a significant effect ($P = 0.05$) at the Meiners site in 1986. Moldboard vs. paraplow and depth vs. fumigation comparisons also had significant effects on root length at the Meiners site (Table 3). There also was a significant interaction ($P = 0.01$) between moldboard and paraplow tillage on root length. In contrast to the Ferrel site, there was a significant interaction ($P = 0.01$) between root length and fumigation.

There was significantly more root length in the paraplow-tilled plots 10–20 cm deep at the Ferrel site in 1986 (Table 4); below this level, no trends attributable to either treatment were obvious. At the Meiners site, root density tended to be greater in the paraplow-tilled plots than in the moldboard-tilled plots. Fumigation did not increase root length. At both sites in 1987, increases in root length were significantly greater in fumigated and paraplow-tilled plots than in nonfumigated moldboard-plowed plots (*data not shown*), and root density was greatest at the 10- to 20-cm depth with paraplow

Table 2. Effect of fumigation on inoculum density of *Fusarium solani* f. sp. *pisi* at different soil depths

Field location	Treatment	Colony-forming units per gram of soil at soil depth indicated			
		0–10 cm	10–20 cm	20–30 cm	30–40 cm
		1986			
Ferrel	Control	367 bcd[z]	387 bc	557 ab	617 a
	Fumigation	10 f	69 ef	150 def	240 cde
Meiners	Control	813 a	753 a	413 b	180 b
	Fumigation	127 b	218 b	330 b	280 b
		1987			
Ferrel	Control	1,246 a	1,180 a	1,020 ab	753 b
	Fumigation	0 c	0 c	0 c	207 c
Meiners	Control	1,600 a	1,267 ab	800 bc	887 bc
	Fumigation	627 cd	540 cd	540 cd	427 cd

[z]Means obtained from a composite of three soil cores for each depth increment at each site. Data are averages of 20 sites per treatment. Means followed by the same letter at each field site and each year are not significantly different according to the LSD test ($P = 0.05$).

Table 3. Orthogonal comparisons of tillage vs. fumigation on root density of green peas in 1986

ANOVA table source of variation	Ferrel site		Meiners site	
	Mean square	*F*	Mean square	*F*
Block	1.7338	···	1.4886	0.6001
Treatment	13.6204	1.8182	5.1555	2.0783*[z]
Error	7.4910	···	2.4807	···
Moldboard vs. paraplow	20.0751	2.680*	39.0150	15.727**
Control vs. fumigation	0.7884	0.105	9.2504	3.972*
Tillage vs. fumigation	0.0026	0.000	0.2400	0.097
Shallow vs. deep	29.5926	3.950*	4.4204	1.782
Depth vs. tillage	112.8824	15.069*	1.0417	0.420
Depth vs. fumigation	0.3151	0.042	10.5337	4.246**

[z]* = Significant at $P = 0.05$ level, ** = significant at $P = 0.01$ level.

tillage plus fumigation.

Penetrometer data (*not shown*) from both field sites in both years did not differ significantly among treatments. However, a trend toward lower penetrometer readings (reduced compaction) in the 20- to 30-cm increment was associated with paraplow tillage both years at both sites.

Fumigation at the Ferrel site significantly reduced the amount of root disease in both the paraplow and the moldboard treatments compared with that in the nonfumigated plots in 1986 (Table 5). Seed yields were significantly greater with paraplow than with moldboard tillage. There were no significant differences in fresh plant weights in any treatment. At the Meiners site, only fumigation in the moldboard-tillage treatment reduced plant disease severity (Table 5). Fresh weights of plants were greatest in both the moldboard and paraplow fumigated plots, and seed yields were significantly greater in the paraplow fumigated plots.

Fumigation significantly reduced plant disease severity and increased seed yields in both the moldboard and the paraplow treatments at the Ferrel site in 1987 (*data not shown*). In addition, fresh plant weights were greater in the fumigated plots. Although fumigation did not reduce disease severity at the Meiners site in 1987, seed yields were significantly higher in fumigated moldboard- and paraplow-tillage plots than in control plots.

DISCUSSION

One important factor that affects pea productivity in the Pacific Northwest is Fusarium root rot (7–9). Peas are infected by *F. s.* f. sp. *pisi* soon after seed imbibition and germination. Chlamydospore germination resulting in root infection is directly influenced by root and seedling exudates and by soil moisture (4,5,7). Although infected early, roots of field-grown plants usually do not show symptoms until 2–3 wk after emergence. Any factor that stresses the host plant can predispose it to *Fusarium* and shorten the incubation period (7).

Fumigation was not as effective in reducing soil populations of *F. s.* f. sp. *pisi* at the Meiners site as at the Ferrel site. The Meiners site is at a higher elevation with more rainfall, is cooler, and has finer-textured soil (Table 1), which most likely restricted fumigant movement. In both 1986 and 1987, root length increased when *Fusarium* inoculum and/or soil mechanical impedance decreased (paraplow tillage). The penetrometer data indicated that paraplowing was indeed effective in reducing compacted soil in the 0- to 30-cm depth range.

A field study completed in southeastern Washington and northeastern Oregon found a characteristic plow pan at a depth of about 20 cm in pea and wheat fields (1). It was also determined that *Fusarium* was present in the plow pan, as deep as pea roots penetrated. The work reported here illustrates that soil compaction and *F. s.* f. sp. *pisi* are yield constraints in the green pea production area of southeastern Washington. This study illuminated the importance of compaction in aggravating root disease stress caused by *F. s.* f. sp. *pisi*. Unfortunately, the yield response was not as dramatic as that reported previously for peas in the Columbia Basin of central Washington (6–8). In the Pacific Northwest, root rot of bean (*Phaseolus vulgaris* L.), caused by *F. s.* f. sp. *phaseoli* (Burk.) Snyd. & Hans., is also aggravated by soil compaction (7). Subsoiling to break compacted layers resulting from tillage was also shown to lessen the effects of bean root rot.

The benefits from reduced populations of *F. s.* f. sp. *pisi* and soil compaction on increased root density and seed yields was somewhat lessened by moisture stress during the growing year. There is evidence, from penetrometer readings, that the tillage pans at both research sites were reduced by paraplow tillage. The effects were not long-lasting, however, and pans formed rapidly after secondary tillage and incorporation of residue before peas were planted (D. E. Wilkins, *unpublished*).

Recent work demonstrated that inoculum of *F. s.* f. sp. *pisi* caused very little disease when placed below 10 cm (11). When inoculum was mixed throughout the 30-cm root profile or in the top 10 cm of soil, however, root disease was severe regardless of amount of inoculum tested. This work illustrates the interaction of the plow layer with pea root health. When tillage pans restrict pea roots to the top layer of soil, Fusarium root rot can be severe. Environmental stresses, including soil compaction, influence the loss of carbon by a living root system, and excessive soil compaction affects the rate and distribution of roots. The abnormal loss of nutrients and the decreased growth rate of roots increases the chances of successful host-pathogen contact (1). The form and rate of root growth, the location of pathogen inoculum, and the biology of both root and pathogen are all influenced by soil structure.

Table 4. Effect of tillage, fumigation, and soil depth on pea root length at two sites in 1986

Field location	Treatment	Root length (cm) per cubic centimeter of soil at soil depth indicated			
		0–10 cm	10–20 cm	20–30 cm	30–40 cm
Ferrel	Moldboard: Control	9.3 abc[z]	7.2 c	11.1 ab	12.1 a
	Fumigation	7.7 bc	8.6 abc	9.9 abc	11.2 ab
	Paraplow: Control	10.6 abc	12.0 a	11.5 a	9.2 abc
	Fumigation	11.0 ab	11.5 a	11.2 ab	10.2 abc
Meiners	Moldboard: Control	6.9 ab	6.2 ab	7.2 ab	6.8 ab
	Fumigation	6.2 ab	5.4 b	6.7 ab	6.6 ab
	Paraplow: Control	8.7 a	8.5 a	7.6 ab	7.8 ab
	Fumigation	6.5 ab	7.0 ab	8.6 a	7.6 ab

[z] Means are an average of six soil cores per replication with six replications per treatment. Data were analyzed separately for each location. Means followed by the same letters are not significantly different ($P = 0.05$).

Table 5. Effect of tillage and fumigation on plant growth, disease severity, and seed yield of green peas in 1986

Field location Treatment	Plant fresh weight (g/plant)	Disease severity	Seed yield (g/plot)
Ferrel			
Moldboard: Control	22.3 a[x]	4.5 a[y]	1,028.0 a[z]
Fumigation	22.3 a	0.9 b	1,080.0 a
Paraplow: Control	23.7 a	4.5 a	1,165.5 b
Fumigation	23.3 a	1.9 b	1,270.0 b
Meiners			
Moldboard: Control	11.7 b	2.7 a	972.8 a
Fumigation	15.5 a	1.4 b	883.0 a
Paraplow: Control	12.0 b	2.4 a	948.7 a
Fumigation	14.2 a	2.6 a	1,023.8 b

[x] Each mean is an average of 25 plants harvested per replication of six replications per treatment. Only fresh weights of plant tops were measured. Means followed by the same letter are not significantly different ($P = 0.05$).

[y] Disease severity index was based on a 0–5 scale, where 0 = healthy and 5 = completely rotted root system. Means followed by the same letter are not significantly different ($P = 0.05$).

[z] Each mean is an average from four plots. Means followed by the same letter are not significantly different ($P = 0.05$).

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