Influence of Soil Bulk Density on Root Rot and Wilt of Chickpea

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ABSTRACT

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The reaction of chickpeas (*Cicer arietinum*) to wilt and root rot pathogens was studied in a loose and a compacted soil with bulk densities of 1.2 $Mg \cdot m^{-3}$ and 1.5 $Mg \cdot m^{-3}$, respectively. Compacted or loose soil was infested separately or in various combinations with *Fusarium oxysporum* f. sp. *ciceri*, *F. solani* f. sp. *pisi*, *Pythium ultimum*, and/or *Thielaviopsis basicola*. The effects of wilt and root rot pathogens on disease severity were additive with various combinations of pathogen-infested soil. Root disease of a susceptible cultivar (JG-62) was more severe in infested, compacted soil than in loose soil. However, soil compaction had no effect on wilt caused by *F. oxysporum* f. sp. *ciceris*. Root growth of chickpea was inversely related to soil compaction.

Additional keywords: fungal interactions, rhizosphere populations

Excessive soil compaction can reduce growth and yield of many crop species (11,23,25,27,30) including chickpeas (*Cicer arietinum* L.) (9). Previous research on beans (*Phaseolus vulgaris* L.) and peas (*Pisum sativum* L.) has shown that compacted soil reduces yield and increases root rot incidence and severity (4,6,14,16,28). Excessive soil compaction reduces growth and distribution of roots and enhances exudation, increasing the chances of successful host-pathogen contact (1).

Kraft and Giles (15) reported that soil compaction decreases yields and increases root rot of peas grown in a sandy loam soil infested with *Fusarium solani* (Mart.) Sacc. f. sp. *pisi* (F.R. Jones) W. C. Snyder & H.N. Hans and *Pythium ultimum* Trow. Currently, chickpeas are being grown in the Pacific Northwest, where root diseases and soil compaction are prevalent (2,6). The objective of this study was to determine the effect of soil compaction on the severity of wilt and root rot caused by several fungal pathogens of chickpeas.

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MATERIALS AND METHODS

A Moxee silt loam soil with 39% sand, 57% silt, 3.6% clay, and a pH of 6.9 was used for all studies reported here. The soil was passed through a 3-mm screen and fumigated with methyl bromide (1.0 kg/m^3 of soil) to eliminate a residual population of *Rhizoctonia solani* Kühn. Fumigated soil was then stored at room temperature for 30 days until used. Fifty-four kilograms of fumigated soil was infested with *F. oxysporum* Schlechtend.:Fr. f. sp. *ciceri* (Padwick) Matuo & K. Sato, *F. solani* f. sp. *pisi*, or *Thielaviopsis basicola* (Berk. & Broome) Ferraris (syn. *Chalara elegans* Neg Raj & Kendrick) at 2,000 propagules per gram or with *P. ultimum* at 200 propagules per gram, as previously described for studying Fusarium wilt of peas (13).

Infested soils were mixed proportionately to obtain test soils infested with four pathogens in all possible combinations. Air-dry test soils were rewetted with filtered water (0.45 μm) to approximate −40 kPa matric potential (18% moisture) before compaction treatments.

The procedure of Burke et al (4) was followed to produce two soil bulk density levels. These levels, expressed as megagrams per cubic meter of soil, were 1.2 $Mg \cdot m^{-3}$ and 1.5 $Mg \cdot m^{-3}$, which represented a loose and a compact soil, respectively. Infested and noninfested soils were placed in the bottom 15 cm of 10-cm diameter, rigid plastic tubes (PVC columns), which were 20 cm long. A 17.5-cm square plastic sheet covered with a 2.5-cm mesh wire of similar size clamped at the bottom held the soil inside the column. A vibrating table and a machine shop drill press with an adapted piston were used to create a compacted soil. A gamma ray attenuation scanning technique (12) was used to determine soil bulk density in the PVC columns.

Measurement of the resulting bulk densities with the gamma ray attenuation apparatus indicated that uniform compaction (1.5 $Mg \cdot m^{-3}$) was obtained with gradual compression of the soil (2.5 kg) in tubes for 1 min, except for a more compact thin layer at the top and another at the bottom. A 1.2-$Mg \cdot m^{-3}$ bulk density was obtained by using 2 kg of soil without compression. To permit contact of chickpea roots with soil at the desired bulk density, a 5 × 5 cm cylinder of soil from the top center of packed soil substrate in each large tube was removed with an auger and replaced with another 5-cm diameter × 15 cm rigid plastic tube containing five chickpea seeds in loosely packed, pathogen-free soil (Fig. 1). In each tube assembly, soil water was maintained at −26 to −40 kPa (12–18% moisture) by adding water to the small tube to bring the unit to the original weight plus the estimated weight of the plants.

The experiment was run twice with three replications per treatment, using a split-plot experimental design, with fungal pathogens as whole plot and soil bulk density as subplot. These experiments were conducted in a controlled environment chamber with a constant temperature of 21 C and a photoperiod of 14 hr at a light intensity of 450 $\mu E \cdot m^{-2} \cdot sec^{-1}$.

Each experiment was harvested 30 days after planting, and plants were scored for wilt and/or root rot severity on a scale of 1 to 9, where 1 is a symptomless plant and 9 is a dead plant (Table

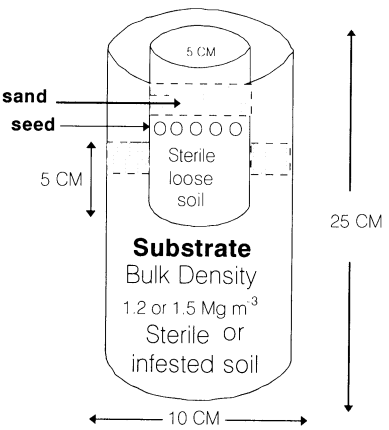

Fig. 1. Tube assembly used to study the effect of soil bulk density on wilt and root rot of chickpea.

1). The rhizosphere soil from the roots of plants in each replication was collected, and pathogen populations alone and in combination were determined using dilution plating techniques and relevant selective media (17,19,26) for each pathogen. Hartley's test of homogeneity of variances (10) was performed to determine whether the results of two experiments could be combined. Data from the two experiments were averaged and analyzed as a split plot using the MSTAT statistical package (18). Treatment means were separated using Fisher's protected least significant difference ($P = 0.05$). Mutually orthogonal contrasts among the treatment totals were constructed to compare the effect of combination treatments with the average of individual effects.

RESULTS

Variances of the two experiments were homogenous according to Hartley's test of homogeneity of variances (10); the results were therefore combined. Chickpea plants grown in soil infested with any pathogen alone or in combination exhibited wilt or root rot symptoms in both loose and compacted soils. Plants grown in soil infested with *F. s. pisi* or *T. basicola* had significantly more root rot in compacted soil than in loose soil (Table 1). Plants wilted and died in the soil infested with *F. o. ciceri* both in the compact and the loose soil (Table 1). Soil compaction did not affect the severity of chickpea root rot in the soil infested with *P. ultimum* (Table 1).

Plants grown in soil infested with a combination of *F. s. pisi* and *T. basicola* had significantly ($P = 0.05$) more root rot than plants grown in soil infested with *F. s. pisi* alone at either soil bulk density (Table 1). Root rot caused by the combination of *F. s. pisi* and *P. ultimum* in the loose soil was as severe as that caused by each pathogen alone; in compacted soil, disease caused by this combination was more severe than in loose soil (Table 1).

Table 1. The effect of wilt and root rot pathogens alone and in combination on disease severity of chickpea at different soil bulk densities

Pathogens[a]	Wilt and root rot severity[b]	
	Loose soil[c]	Compacted soil
FOC	7.50[d]	8.00
FSP	3.25	4.75
PU	4.00	4.50
TB	5.08	6.53
FOC + FSP	8.47	8.75
FOC + PU	6.17	7.08
FOC + TB	8.00	8.92
FSP + PU	3.92	5.58
FSP + TB	5.17	7.02
PU + TB	5.33	6.50
FOC + FSP + PU	8.33	8.92
FOC + FSP + TB	8.83	8.50
FSP + PU + TB	5.58	7.83
FOC + FSP + PU + TB	8.08	8.83
Check	1.08	1.00

[a] FOC = *Fusarium oxysporum* f. sp. *ciceri*, FSP = *Fusarium solani* f. sp. *pisi*, PU = *Pythium ultimum*, TB = *Thielaviopsis basicola*.

[b] Wilt and root rot severity scale: 1 = no visible disease symptoms; 3 = very few discolored leaves (<10%) and/or <10% root and hypocotyl tissue covered with small lesions; 5 = approx <25% of foliage exhibits chlorosis, with small lesions on roots and slight vascular discoloration, and/or approx <25% of the root and hypocotyl tissue covered with lesions; 7 = approx <50% of foliage exhibits wilting and chlorosis, limited necrosis and stunted plant growth, and/or coalescing of lesions (approx <50% of root and hypocotyl tissue covered with lesions), with considerable softening and rooting of the root system; 9 = >50% of foliage exhibits wilting and chlorosis with vascular discoloration, often resulting in death of plant, and/or >50% of hypocotyl and root tissue affected with advance stage of rotting combined with severe reduction of the root system. Numbers 2, 4, 6, and 8 were assigned to plants showing symptoms between the appropriate odd number ratings.

[c] Soil bulk densities were 1.2 $Mg \cdot m^{-3}$ for loose soil and 1.5 $Mg \cdot m^{-3}$ for compacted soil.

[d] Means were separated using Fisher's protected least significant difference (LSD). LSD 0.05 within columns = 0.71; LSD 0.05 within rows = 0.88.

Table 2. Orthogonal comparisons of different combinations of wilt and root rot pathogens on disease severity of chickpea cv. JG-62

Source of variation[a]	df	Soil bulk density			
		1.2 $Mg \cdot m^{-3}$		1.5 $Mg \cdot m^{-3}$	
		Mean square	*F*	Mean square	*F*
Block	2	0.2	0.6	0.2	0.6
Treatment	15	26.9	74.6	26.9	74.6*[b]
FOC & FSP alone vs. together	1	17.5	48.5**	11.2	31.3**
FOC & PU alone vs. together	1	6.7	18.6**	0.8	2.4*
FOC & TB alone vs. together	1	1.6	4.6**	1.1	3.2*
FSP & PU alone vs. together	1	12.9	35.8**	12.0	33.5**
FSP & TB alone vs. together	1	2.1	6.0**	3.7	10.5**
PU & TB alone vs. together	1	24.5	67.9**	23.1	64.2**
Each alone vs. all together	1	9.2	25.6**	7.0	19.6**
Check vs. all combinations	1	79.1	219.5**	113.3	314.6**
Error		30.3	...	...	...

[a] FOC = *Fusarium oxysporum* f. sp. *ciceri*, FSP = *Fusarium solani* f. sp. *pisi*, TB = *Thielaviopsis basicola*, PU = *Pythium ultimum*.

[b] * = Significant at $P = 0.05$; ** = significant at $P = 0.01$.

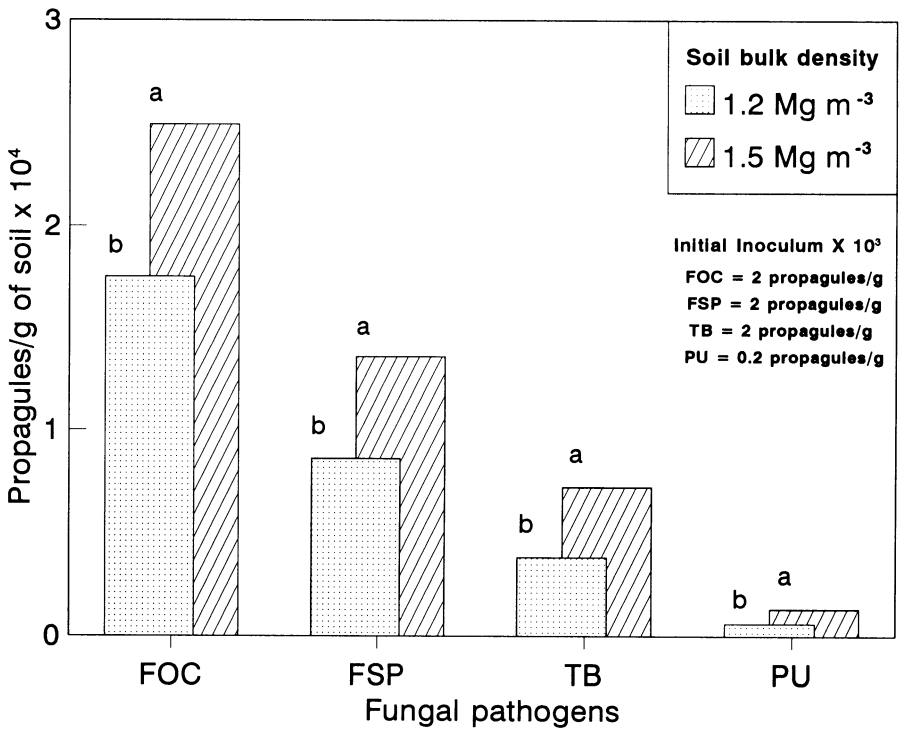

Fig. 2. Rhizosphere populations of wilt and root rot pathogens of chickpea after 30 days in previously infested loose and compact soils. FOC = *Fusarium oxysporum* f. sp. *ciceri*, FSP = *F. solani* f. sp. *pisi*, PU = *Pythium ultimum*, and TB = *Thielaviopsis basicola*. Bars with the same letter are not significantly different from one another according to Duncan's multiple range test ($P = 0.05$).

The combination of *F. o. ciceri* with *F. s. pisi* and/or *T. basicola* caused more severe disease than either of these root rot pathogens alone (Table 2). However, when *F. o. ciceri* was present as part of a pathogen combination, wilt symptoms predominated, and the effect of soil compaction on wilt severity was not significant ($P > 0.05$). Root rot was more severe in compact soil when *T. basicola* was present with the other root rot pathogens (Tables 1 and 2).

Chickpea plants grown in compacted soil infested with both *F. o. ciceri* and *P. ultimum* showed wilt symptoms similar to those grown in soil infested with *F. oxysporum* alone. In loose soil, however, wilt was suppressed in soil infested with both pathogens (Table 1). Wilt or root rot caused by different combinations of wilt and root rot pathogens was generally more severe than the average of the disease caused by individual pathogens in either loose or compacted soils (Table 2).

The populations of all four fungal pathogens increased significantly more in compacted than in loose soil. In soil infested with the four root pathogens, alone or together, the rhizosphere population of *F. o. ciceri* increased the most, followed by *F. s. pisi* (Figs. 2 and 3).

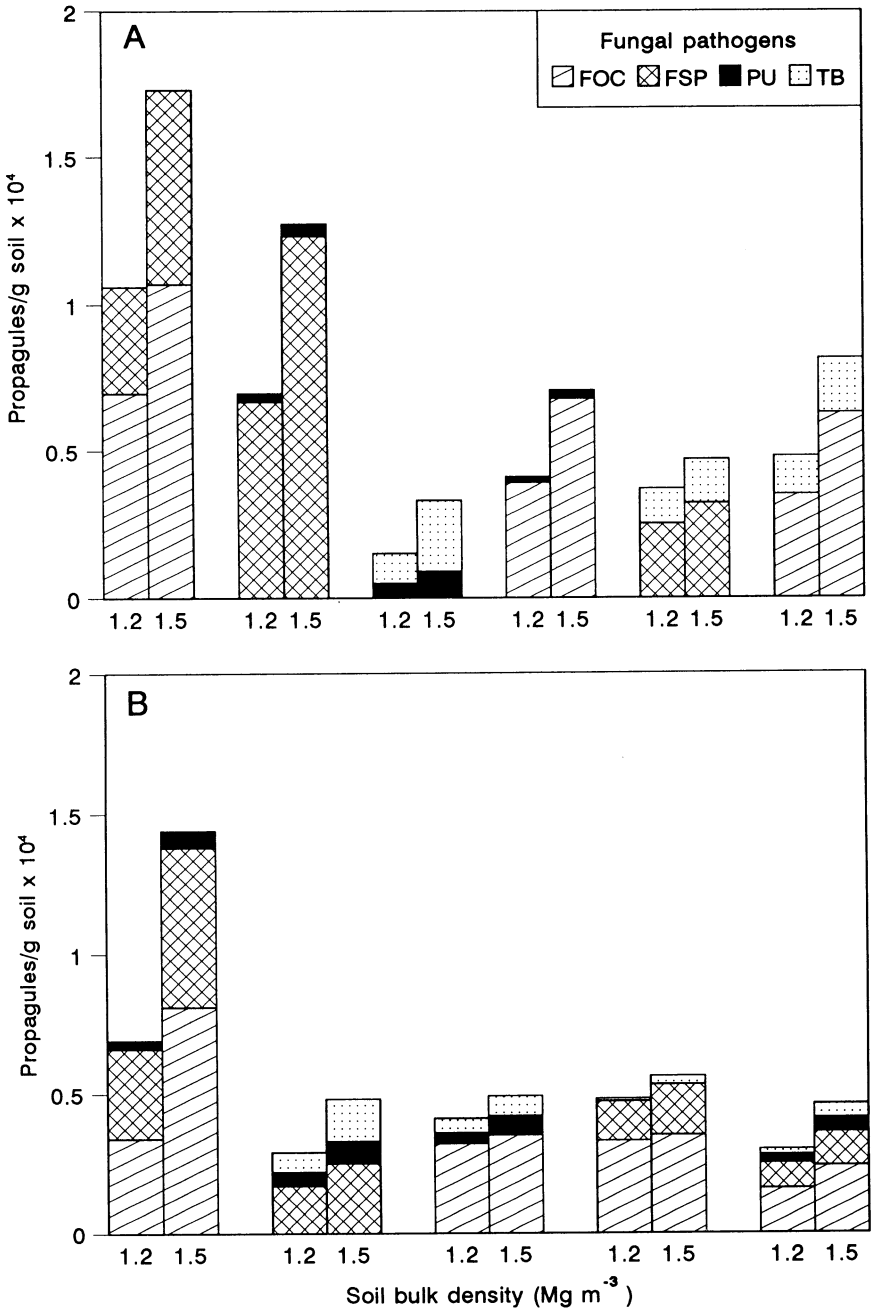

Fig. 3. Rhizosphere populations of wilt and root rot pathogens of chickpea in different combinations from soil infested with equal proportions of inoculum and maintained at two soil bulk densities: **(A)** combination of two pathogens; **(B)** combination of three pathogens. FOC = *Fusarium oxysporum* f. sp. *ciceri*, FSP = *F. solani* f. sp. *pisi*, PU = *Pythium ultimum*, and TB = *Thielaviopsis basicola*.

DISCUSSION

Chickpea root growth, as with other crops (1,11,30), is restricted by compacted soil (9). In general, root growth increased above the compact substrate soil, which probably compensated for decreased growth within the compacted soil. Bulk density of the substrate soil had little effect on the total shoot weight or leaf area of chickpea plants. However, roots of plants in compacted soil were thicker and were clustered above the restrictive layer, mostly in the small tubes. Root growth of beans was similar (16).

Soil bulk density had significant ($P = 0.05$) effects on the severity of root rot caused by *F. s. pisi* and *T. basicola*. As with peas and beans (3–6,15,28), chickpea root rot was more severe in the compacted soil than in the loose soil. Exudation from healthy roots is greatest near the root tip and along the zone of elongation (24,25). Chlamydospore germination resulting in root infection is directly influenced by root and seedling exudates and by soil moisture (8,21). Any factor such as soil compaction that stresses the host plant can predispose it to Fusarium root rot and shorten the incubation period (1,4,6,14). Compaction predisposed chickpea plants to Fusarium and Thielaviopsis root rot. Typical necrotic symptoms on the hypocotyl and epicotyl caused by *F. s. pisi* were not obvious in the compacted soil tubes. This was because seeds were germinated in noninfested loose soil, and early infection of the cotyledonary attachment area was prevented. Future studies will require germinating seeds in an infested soil medium.

Soil bulk density had no significant effect ($P = 0.05$) on wilt severity caused by *F. o. ciceri*. Root tips growing through infested, loose soil would encounter infective inoculum (20). In contrast, the rhizosphere population of the wilt pathogen almost doubled in the presence of exudates from secondary root growth in compacted soil where the likelihood of obtaining sufficient nutrients for germination of chlamydospores was greatest. Thus, the increased inoculum density caused as much wilt in the compacted soil as in the loose soil. Similar to pea wilt (20), chickpea wilt severity increased with an increase in the number of infection sites and inoculum density.

Wilt symptoms from *F. o. ciceri* were suppressed in loose soil that was infested with *P. ultimum* also. Suppression of wilt in the presence of *P. ultimum* was observed at different soil matric potentials (Bhatti and Kraft, *unpublished*). Such suppression was not observed in the compacted soil, where the root tips (infection sites) were confined to a compact layer and where exudates led to a proportionally higher population of *F. oxysporum* in the rhizosphere (Table 1).

The combinations of *F. o. ciceri*, *F.*

s. pisi, and/or *T. basicola* on chickpea wilt or root rot severity were additive. The disease severity in treatments with two or more pathogens was significantly greater than the average of their individual effects. Worf and Hagedorn (29) reported similar interactions between *F. o. pisi* and *F. s. pisi* on peas. The site of infection for *F. s. pisi* is the cotyledonary attachment area. Root tips are infection sites of *F. o. ciceri* (20), whereas *T. basicola* is a cortical rot pathogen (21). Consequently, neither *F. s. pisi* nor *T. basicola* would be expected to interfere with the wilt fungus if it invades through root tips.

Increases in disease severity and rhizosphere populations of both *Fusarium* species were noted when *T. basicola* was present. Pierre and Wilkinson (22) noted that direct penetration by *T. basicola* through epidermal cells facilitates the penetration of *F. s. phaseoli* through stomata. Our results suggested that infection by *T. basicola* predisposed roots of chickpea to severe infection by *F. s. pisi* or *F. o. ciceri*. Frequent recovery of *T. basicola* from diseased roots of chickpeas indicated that *T. basicola* is an important component of the chickpea root disease complex in eastern Washington and northern Idaho.

F. o. ciceri was a prolific root colonizer either alone or in combination with other root pathogens in this study. However, the population of wilt and root rot pathogens was significantly higher in compacted soil than in loose soil. Soil compaction is known to reduce root growth and enhance exudation, thus affecting the probability of successful host-pathogen contact and the dynamics of root-pathogen interactions. All the pathogens studied in this report exist as dormant spores in soil and are stimulated by exudates to germinate, grow, and infect nearby roots or seed. Exudates of chickpeas in the rhizosphere in compacted soil apparently can promote high populations of these chickpea root pathogens.

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