Influence of Soil Bulk Density and Water Potential on Fusarium Root Rot of Beans

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ABSTRACT

The influence of soil bulk density and water potential on injury to beans by Fusarium root rot was evaluated in the laboratory. A technique was used by which soil water potential could be maintained relatively constant, without the alternate wetting and drying that accompanies periodic irrigation. Growth of tops and roots was consistently reduced by decreasing water potential from −200 to −800 mb. Yields of tops and of roots within or above a restrictive soil layer were lower in infested soil than in fumigated soil. However, the roots that penetrated the layer grew equally well and were healthy in both soils. The bulk density of a central soil layer had little effect on top yields. In fumigated soil, root growth above the most-dense layer was greater than above the less-dense layers; while in root rot soil, root growth above the layer was not affected by layer bulk density. The detrimental effects of decreased water potential, *Fusarium* infestation, and increased layer bulk density were additive.

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Additional key words: Phaseolus vulgaris L., soil compaction, root impedance.

The bean (*Phaseolus vulgaris* L.) root pathogen *Fusarium solani* (Mart.) Appel & Wr. f. sp. *phaseoli* (Burk.) Snyd. & Hans. has little influence on yields of plants that have vigorously growing roots (1). We found that Fusarium root rot was aggravated by compact soil (bulk density of 1.5 to 1.6 g/cm^3) and that its yield-depressing effects were greatly reduced when disk and plow soles were broken by subsoiling immediately before planting (2, 3). Subsoiling allowed roots to extend through surface soil heavily infested with *Fusarium* into sparsely infested subsoil. Without subsoiling, most roots remained in the infested surface soil, which resulted in serious injury and yield reduction. In these previous studies, the effects of root rot injury were not separated from the effects of reduced rooting volume and water and nutrient uptake. Also, in field studies, it is difficult to separate the effects of soil water potential and root impedance because of variations in soil compaction and soil water content. This paper reports a laboratory study of the effects of soil water matric potential and root impedance by soil layers on injury to bean growth by *Fusarium solani* f. sp. *phaseoli*.

MATERIALS AND METHODS.—Bulk soil was obtained from the surface (0 to 15 cm) and subsoil (60 to 75 cm) of Warden loam that had been cropped to beans for about 15 yr. The surface soil contains about 48% sand and 12% clay; the subsoil is silt loam with about 23% sand and 14% clay. Dilution plate counts showed that the surface soil was heavily infested (200 to 500 propagules/g) with *Fusarium solani* f. sp. *phaseoli*, but the population was negligible in the subsoil. A portion of each soil was fumigated (1.5 g methyl bromide/kg of soil) to eliminate the pathogen. All soil was then air-dried, passed through a 1-mm sieve, and stored in covered metal barrels for subsequent use.

The surface soil was fertilized with 50 ppm nitrogen as ammonium sulfate and 5 ppm zinc as zinc ammonium sulfite with 4% manganese as an impurity. Soil tests indicated adequate phosphorus and potassium. The subsoil was not fertilized. The soil was mixed with sufficient water to bring the water content to 16 to 17% by weight, and allowed to equilibrate for several days. Then it was packed in slabs between two plates, one of which was the porous ceramic side of a suction chamber (Fig. 1). The soil slabs were 1.5-cm thick, 32-cm high, and 17-cm wide. The bottom 14 cm was subsoil at a bulk density of 1.2 g/cm^3. Immediately above was a 4-cm layer of surface soil packed to bulk densities of 1.2, 1.4, or 1.55 g/cm^3. These layer densities covered the range observed in the field at planting time (2), with the highest density representing that of a tillage pan.

After packing, the slabs were equilibrated overnight at

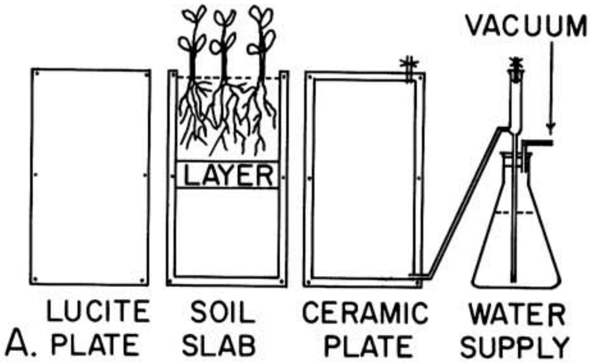

Fig. 1-(A, B). A) Diagram of apparatus used to evaluate effects of soil water matric potential, soil layer bulk density, and root rot infestation on growth of beans. Soil slab is clamped between the lucite and ceramic plates and water potential in the ceramic plate is controlled by regulated vacuum. **B)** The assembled units in use.

a matric potential of −200 millibars (mb) and three bean seedlings ('Red Mexican UI 36') with roots 2-3 cm long were transplanted into each. The planted seedlings were covered with sand to reduce evaporation and the units were placed under fluorescent lights (50% cool white, 50% violet growth lights) with a cycle of 16 h on and 8 h off. Light intensity near the top leaves was about 12,912 lx (1,200 ft-c). Room temp varied between about 22 and 26 C. All units were maintained at −200 mb potential until the roots approached the 4-cm layer (about 5 days after planting). At this time a matric potential of −800 mb was applied to every other unit, and these two values (−200 and −800 mb) were maintained throughout the growth period. Four weeks after planting, the tops were harvested and weighed, the soil was washed away and the fresh weight of roots in each section of soil was determined. Water use rates were measured at 10, 18, and 27 days after planting.

The study was set up in a factorial design with three replications with the main factors as:

Soil: Fusarium-infested or fumigated

Water potential: −200 or −800 mb

Layer bulk density: 1.2, 1.4, or 1.55 g/cm^3.

Soils and bulk densities were completely randomized within a replication, whereas low and high potential units were alternated.

Several of the ceramic membranes failed during the study, so only two replications were completed. The experiment was repeated to obtain two additional replications and the results are based on the four replications. A preliminary nonreplicated test gave essentially the same results.

The use of a ceramic plate, as discussed here, maintains the soil water at near constant potential through regulation of the vacuum applied to the water supply. As water is used from the soil by evapotranspiration, it is replaced by water flowing from the ceramic into the soil. Similar techniques have been discussed by Kramer (5). This type of water potential control was chosen over the osmotic method of Cox and Boersma (4) because of the rapid microbial deterioration of the membranes which occurred when we attempted to use their technique. The ceramic plate method had several limitations, the most important of which was that the minimum potential possible was about −800 mb. Lower potentials would have been desirable to simulate those often encountered in the field. Roots were more concd near the soil:ceramic interface than in the bulk soil. However, the soil slabs were thin enough (1.5 cm) that this effect was not considered to be important. Soil matric potentials were monitored in some of the units with tensiometers. Near the end of the study, when water use rates were highest, potentials became lower than the intended values because water did not flow from the ceramic through the soil as fast as it was transpired. This effect was not considered to be serious, however, inasmuch as control of potential was adequate during root growth and penetration through the soil.

RESULTS.—*Soil water potential.*—Plant growth (tops and roots) was consistently reduced by decreasing water potential from −200 to −800 mb (Table 1). Water stress symptoms were often visible in the plants grown at the lower potential (darker green color). Averaged over all the other variables, decreased potential decreased top yields about 40%. There were no interactions between potential and the other variables. Water use rates also dropped as potential decreased (Table 2).

Fusarium-infested vs. fumigated soil.—Yields of tops and of roots within or above the central layer were significantly less in the infested soil than in the fumigated soil (Table 3). When roots penetrated through the layer, however, they grew equally well in both soils.

TABLE 1. Fresh weights of bean tops and roots as affected by soil water potential[a]

Water potential	Bean tops	Bean roots with respect to subsurface layer: Above	Within	Below	Total
mb	------------grams per unit------------				
−800	15	7	1	4	12
−200	25**[b]	9**	2**	8**	19**

[a]Each value is the average from two soil and three bulk density variables 28 days after planting.

[b]Significantly different, $P = 0.01$.

TABLE 2. Effect of soil water potential and bulk density of a subsurface layer on water use rates by beans in *Fusarium*-infested vs. fumigated soil at 10, 19, and 27 days after planting

Water potential of soil (mb)	Bulk density of subsurface layer (g/cm³)					
	Fumigated soil			Fusarium-infested soil		
	1.2	1.4	1.55	1.2	1.4	1.55
	--------grams per unit per 24 hours--------					
	10 Days after planting					
−800	45	36	32	41	37	33
−200	59	70	67	66	47	56
	Potentials**[a]					
	19 Days after planting					
−800	87	80	58	64	58	54
−200	122	108	128	119	80	98
	Potentials**					
	27 Days after planting					
−800	78	115	89	82	62	40
−200	160	161	185	130	95	129
	Soils**; Potentials**					

[a]Significantly different, $P = 0.01$.

TABLE 3. Effect of soil water potential and bulk density of a subsurface layer on fresh weights of bean tops and roots in *Fusarium*-infested vs. fumigated soil

Water potential of soil (mb)	Bulk density of subsurface layer (g/cm³)					
	Fumigated soil			Fusarium-infested soil		
	1.2	1.4	1.55	1.2	1.4	1.55
	-----------Bean tops (g/unit)-----------					
−800	19	20	17	13	12	11
−200	31	28	32	22	16	20
	Soils**[a]; Bulk density N.S.					
	----Roots above layer (0 to 14 cm) (g/unit)----					
−800	7	9	11	4	4	6
−200	10	9	15	6	6	7
	Soils**; Bulk density**; Soils × bulk density*					
	----Roots within layer (14 to 18 cm) (g/unit)----					
−800	2	1	0	1	0	0
−200	2	2	2	2	1	1
	Soils**; Bulk density**					
	----Roots below layer (18 to 32 cm) (g/unit)----					
−800	7	7	0	6	4	0
−200	9	9	7	11	7	8
	Bulk density**; Soils N.S.					
	----Total roots (0 to 32 cm) (g/unit)----					
−800	16	17	11	11	9	6
−200	22	20	24	19	13	15
	Soils**; Bulk density N.S.					

[a]** = Significant differences at 1% probability; * = Significant differences at 5% probability; N.S. = Not significantly different at 5% probability.

Water use rates were nearly the same from infested and fumigated soil 10 and 19 days after planting (Table 2). By 27 days after planting, however, root rot was severe enough to interfere with water absorption, and water use rates were less in the infested than in the fumigated soil. The lowest water-use rates were from those plants with root rot, subjected to low water potential and a layer bulk density of 1.55 g/cm³. Under these conditions, roots did not penetrate the layer and the plants were forced to extract water from the restricted volume above the layer through injured roots.

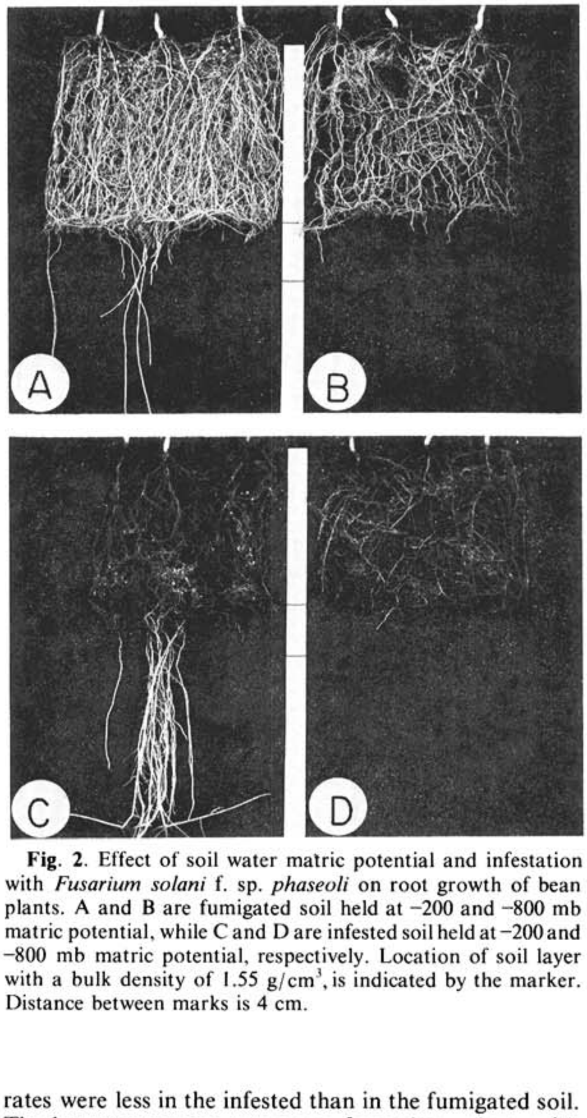

Fig. 2. Effect of soil water matric potential and infestation with *Fusarium solani* f. sp. *phaseoli* on root growth of bean plants. A and B are fumigated soil held at −200 and −800 mb matric potential, while C and D are infested soil held at −200 and −800 mb matric potential, respectively. Location of soil layer with a bulk density of 1.55 g/cm³, is indicated by the marker. Distance between marks is 4 cm.

Bulk density of subsurface layer.—The bulk density of the central layer had little effect on yield of plant tops (Table 3). Although the 1.55-g/cm³ layer restricted root penetration, the plants obtained sufficient water and nutrients from above the layer for adequate top growth. Roots penetrated the layer at a bulk density of 1.4 g/cm³ nearly as well as at 1.2 g/cm³.

In root growth above the restrictive layer there was a significant interaction between layer bulk density and soil treatment. The growth above that layer was greater in the fumigated soil at the highest bulk density than at the lowest bulk density, but in the *Fusarium*-infested soil root growth above the layer was not affected by layer bulk density (Table 3).

At the low soil water potential, no roots penetrated the

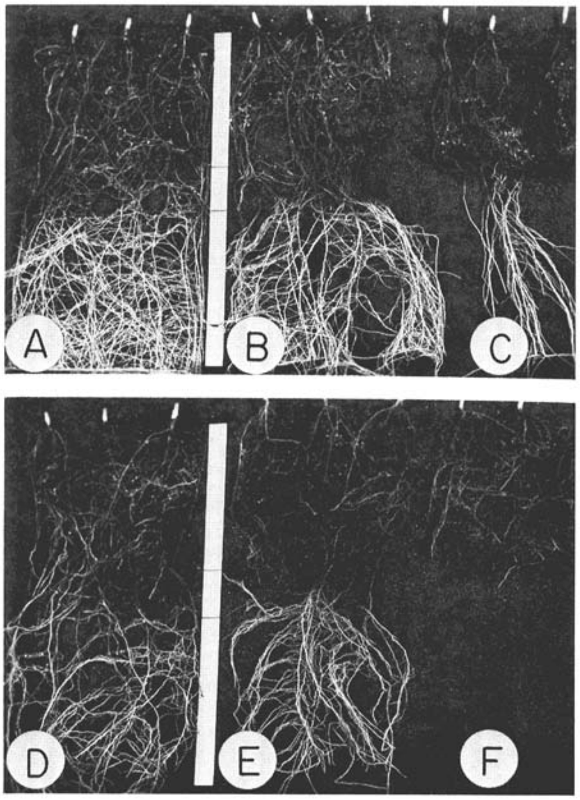

Fig. 3. Effect of soil water matric potential and bulk density of a central soil layer on bean root growth in *Fusarium*-infested soil. A, B, and C were held at −200 mb matric potential with layer bulk densities of 1.2, 1.4, and 1.55 g/cm^3, respectively. D, E, and F were held at −800 mb matric potential with layer bulk densities also of 1.2, 1.4, and 1.55 g/cm^3, respectively. Location of layer with indicated bulk density is shown by the marker. Distance between marks is 4 cm.

layer of *Fusarium*-infested soil compacted to 1.55 g/cm^3 and only one root penetrated the fumigated soil layer. When the impedance was lowered by increasing the potential or decreasing the bulk density, roots penetrated the layer and grew profusely in the subsoil, whether or not it had been fumigated (Table 3, Fig. 2, 3). Figure 2 indicates greater root growth at −200 mb potential below a dense layer in infested soil than in fumigated soil. However, Table 1 shows that root growth below the layer was not influenced by fumigation and Fig. 2 indicates some of the variation encountered.

DISCUSSION.—The detrimental effects of water potential, *Fusarium* infestation, and layer bulk density on plant growth were additive. Plant damage was greatest in infested soil maintained at low potential and with the most compact layer. Conversely, plant yields were highest in fumigated soil without a restrictive layer and maintained at high potential. Penetration of the most compact layer (1.55 g/cm^3) was negligible at low potential, whether or not the *Fusarium* was present. Root penetration was increased by decreasing impedance, either by reducing bulk density or increasing water potential, and those roots that penetrated the layer into the subsoil appeared healthy.

In a previous study (3), we found that subsoiling had little effect on plant yield when soil water was maintained near optimum. The data in Table 1 support these findings in that the yields of tops were not significantly influenced by the bulk density of the soil layer, under conditions where water was not deficient. In the field, soil above a compact layer may dry out enough to cause water stress injury to plants with roots confined above the layer, especially if root density and functions are reduced by root rot. Under such conditions, an interaction between soil water status above the layer and the root impedance by the layer may be expected. Serious water stress injury may be prevented, however, even in *Fusarium*-infected plants, if the soil is kept moist enough. Moisture status of the soil above the layer will be less important when roots can penetrate the layer than when they cannot. Furthermore, roots extending into the subsoil encounter fewer *Fusarium* propagules (2).

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