Effects of Soil Physical Factors on Resistance in Beans to Fusarium Root Rot

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ABSTRACT

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Growth room studies were conducted to determine the responses of dry bean cultivars differing in levels of genetic resistance to *Fusarium solani* f. sp. *phaseoli* as affected by stresses caused by low soil oxygen, low temperature, soil compaction, and low water potentials when grown in *Fusarium*-infested soil. The responses of a susceptible (Red Mexican UI-36), a moderately resistant (Gloria Pink), and a resistant (NY-2114-12) cultivar were compared. Root rot resistance inherent in cultivars Gloria Pink and NY-2114-12 was effective in well-aerated soil but was largely overcome by short periods of poor soil aeration. Resistant cultivar NY-2114-12 compensated for impeded root penetration more than the susceptible cultivars by increasing root growth above the impedance.

Oxygen stress (8,9), soil compaction (3,5), low temperatures (1,2,4), and water stress (7) predispose dry bean (*Phaseolus vulgaris* L.) cultivars susceptible to Fusarium root rot, caused by *Fusarium solani* (Mart.) Appel & Wr. f. sp. *phaseoli* (Burk.) Snyd. & Hans., to the disease. The ability of beans to compensate for a compact soil layer by increasing root growth above the layer is reduced by *Fusarium* infection (7).

This paper reports results of growth room studies to determine the responses of three bean cultivars differing in levels of genetic resistance to *F. solani* f. sp. *phaseoli* to exposure to low soil oxygen, low temperatures, compact subsoil, and low soil water potentials in *Fusarium*-infested soil.

MATERIALS AND METHODS

Three bean cultivars were compared: Red Mexican UI-36, highly susceptible to Fusarium root rot; Gloria Pink, moderately resistant; and NY-2114-12, resistant. The soil used is classified as Warden loam (coarse silty, mixed, mesic Xerollic Camborthids) and contains about 48% sand and 12% clay in the surface. The subsoil is silt loam with about 23% sand and 14% clay.

Temperature and oxygen levels. Procedures were similar to those reported previously (7,8). Beans were grown in field soil that had become infested with *F. solani* f. sp. *phaseoli* by many years of cropping to beans. Although population levels of the pathogen were not determined, plate counts made in previous work (7) showed the surface soil was heavily infested (200–500 propagules per gram) with *F. solani* f. sp. *phaseoli*. Extensive root infection verified that the surface soil contained many propagules of the pathogen. The pathogen population in the subsoil was negligible.

Soil was placed in 36 cells, each 32 cm high, 17 cm wide, and 1.5 cm thick. The bottom 14 cm was subsoil (60- to 75-cm soil depth) at a bulk density of 1.2 g/cm^3. This was overlain by a 4-cm layer of surface soil packed to 1.55 g/cm^3, which simulated a tillage pan. The top layer contained 14 cm of surface soil packed to 1.2 g/cm^3. Each cell was connected to a calibrated water-supply flask under controlled vacuum, and the soil water potential was maintained at −150 mbar. Three germinated seeds per cultivar were planted 1 cm deep in each of 12 cells, and the soil surfaces were covered with 1 cm of fine sand to reduce evaporation. Five days after seedlings emerged, the surfaces of half of the cells of each cultivar were sealed around the seedling stems with tape and paraffin wax, leaving about 0.5 cm between the sand and the seal. Oxygen-nitrogen gas mixtures of 0, 1, or 3% oxygen were passed across the soil surface for 3 days. The seals were then removed so that normal aeration could resume. The control treatment was continuous exposure to room air (21% oxygen).

Water use rates were measured every 1–3 days from the start of the aeration treatments until harvest by measuring the volume of water withdrawn from the calibrated water-supply flasks. Cells were lighted with fluorescent lamps (50% cool-white, 50% violet growth lights, 16-hr photoperiod, 8,500–9,500 lm/m^2) and held at temperatures of about 23 C at night and 26 C during the day. Plants were harvested when 4 wk old, and shoots and roots were weighed. The degree of root injury caused by the pathogen was determined visually with an arbitrary scale of 0 for no injury and 4 for severe injury, where the entire cortex of all roots was rotted.

The study was arranged as a split plot with three replicates; gas compositions were main plots and bean cultivars were subplots. Gas mixtures were controlled by passing compressed air and nitrogen under controlled pressure through porvic flow plugs (6), through a mixing flask, and into a manifold from which the mixture was distributed to appropriate cells. During the 3-day treatment period, the gas composition passing over the soil surface was monitored several times. The mean O_2 percentages for the four treatments were 0.1, 0.9, 3, and 21.

Following this study, the effect of temperature on the responses of these cultivars to low soil oxygen was evaluated. Thirty-six cells were prepared and planted as before. Eighteen cells (six per cultivar) were placed in a growth chamber maintained at constant 27 C, a temperature near optimum for bean plant growth. The remaining cells were placed in another growth chamber at 24 C for 5 days to permit seedling establishment. Temperature in this chamber then was reduced to 18 C, which is unfavorable for bean growth. Aeration variables were imposed on the sixth day in both chambers. These consisted of leaving cells exposed to room air or creating low soil oxygen by passing compressed nitrogen gas (no oxygen) across the surface of the soil within the sealed cells from the sixth through the eighth day after planting. After this 3-day treatment, the sealed cells were opened to the atmosphere. After 2 wk, the low-temperature chamber was warmed to 21 C, a temperature more favorable to bean growth. This temperature was maintained until harvest, when plants were 4 wk old. Within each chamber, cells were arranged in three replicates of a split-plot design with gas composition as main plots and bean cultivars as subplots.

Soil compaction and low soil water potential. Performance of the three bean cultivars was compared at three densities of a subsurface layer and at two soil water potentials. Soil cells were packed as in the previous study, except the 14- to 18-cm depth was surface soil packed to a bulk density of 1.2, 1.4, or 1.55 g/cm^3, simulating tillage pans of varying

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compaction. The study was set up as four replicates of a split-split-plot design with soil water potential as main plots, subsurface layer bulk density as subplots, and bean cultivars as sub-subplots. Inasmuch as only 36 cells were available, the four replicates were conducted in two successive sets of two replicates each.

As before, germinated seeds of the three cultivars were planted three to a cell with soil water potential maintained at −150 mbar. About 5 days after seedlings emerged, and roots were approaching the layer, the soil water potential was decreased on half of the cells to −800 mbar and maintained at −150 mbar on the others. Ambient temperature throughout the experiment was 22–24 C. Water use rates were measured until harvest (4 wk after planting).

RESULTS AND DISCUSSION

Cultivar response to low soil oxygen. Growth characteristics of cultivars UI-36 and Gloria Pink were similar. Compared with these cultivars, NY-2114-12 grew more rapidly and developed longer internodes and smaller leaves. UI-36 and Gloria Pink plants showed characteristic symptoms of stunting and dark foliage color, but most of them partially recovered after resumption of normal aeration. At harvest, lower leaves of UI-36 and Gloria Pink were dead, whereas NY-2114-12 plants remained green regardless of aeration treatment. Loss of lower leaves is characteristic of root rot-susceptible plants under field conditions; more resistant cultivars tend to retain them (D. W. Burke, *unpublished*).

NY-2114-12 usually outyielded UI-36 and Gloria Pink in both shoots and roots (Table 1). With few exceptions, all three cultivars in cells treated with 0% O_2 yielded less than they did in cells receiving O_2. There was little difference among the cells receiving 1% O_2 or more. Root injury was similar for UI-36 and Gloria Pink plants and much greater than for NY-2114-12 (Table 2). There was no consistent effect of O_2 concentration on root disease indices, indicating again (2) that such indices (based on visual estimates) are not valid measures of plant damage by *F. solani* f. sp. *phaseoli*. The subsoil typically contained a low pathogen population (7), and roots that grew into the subsoil were generally healthy.

Water use rates in all cultivars were reduced by the 0 and 1% O_2 compared with air and 3% O_2 treatments, which were about equal. Water use was generally lowest in Gloria Pink and highest in NY-2114-12. Figure 1 shows the water use rates of these two cultivars at the two extreme oxygen concentrations of 0 and 21%. Previous work (8) with fumigated soil and UI-36 has shown that in the absence of *F. solani* f. sp. *phaseoli*, low soil oxygen has little effect on water use after normal aeration is resumed; whereas in soil infested by the pathogen, the reduction in water use is permanent. In our study, in pathogen-infested soil, water use was reduced even in root rot-resistant NY-2114-12; this reduction lasted until harvest.

The level of root rot resistance inherent in Gloria Pink and NY-2114-12 was effective in well-aerated soil but was partially overcome, especially in Gloria Pink, by temporary poor soil aeration. Injury to roots that occurred during the low O_2 period interfered with water uptake by all three cultivars throughout the remainder of the growth period.

Cultivar response to oxygen stress at different temperatures. All cultivars grew more vigorously at constant 27 C than at the lower temperature regime. In both conditions, the period of low soil oxygen reduced yields of all three cultivars by

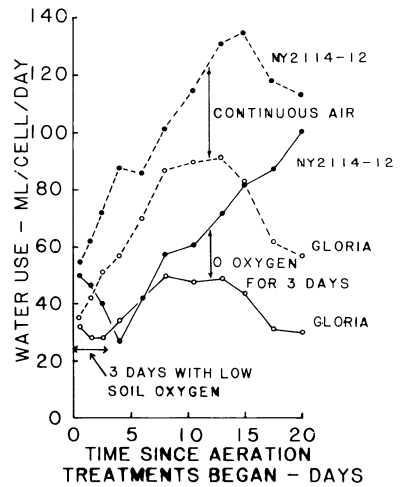

Fig. 1. Daily water use rates by two bean cultivars grown in *Fusarium*-infested soil, as affected by low soil oxygen levels for 3 days.

Table 1. Fresh weights of shoots and roots of three bean cultivars grown for 28 days in *Fusarium*-infested soil as affected by aeration treatment[a]

Treatment	Cultivar	Shoot weights (g/cell)	Root weights (g/cell): Above compact layer	Within compact layer	Below compact layer	Total
0% O_2	UI-36	13.9	6.4	0.9	4.6	12.0
	Gloria Pink	9.4	4.8	0.3	2.3	7.5
	NY-2114-12	17.0	10.0	0.6	2.2	12.8
	Av.	13.4**[b]	7.1	0.6	3.0	10.8
Air	UI-36	17.0	7.6	1.0	2.5	11.1
	Gloria Pink	14.9	6.6	0.6	3.3	10.5
	NY-2114-12	23.4	12.9	1.0	5.0	18.9
	Av.	18.4	9.0	0.9	3.6	13.5
Cultivar means[c]	UI-36	16.7	8.2	0.9	3.3	12.4
	Gloria Pink	15.0	7.2	0.6	2.5	10.3
	NY-2114-12	20.5*	11.0**	0.8	3.4	15.3*

[a]The 1 and 3% O_2 treatments are not shown because results were similar to those from the air treatment.
[b]Zero oxygen treatment means significantly different from air, and cultivar means significantly different from UI-36 (* = $P = 0.05$ and ** = $P = 0.01$).
[c]For all four aeration treatments.

Table 2. Disease indices[a] of hypocotyls and roots of three bean cultivars grown in *Fusarium*-infested soil, as influenced by aeration treatment[b]

Treatment	Cultivar	Hypocotyl	Roots: Above compact layer	Within compact layer	Below compact layer
0% O_2	UI-36	3.7	3.3	2.0	0.2
	Gloria Pink	3.7	3.3	3.0	1.0
	NY-2114-12	1.2	1.3	1.7	0.3
	Av.	2.8	2.7	2.2	0.5
Air	UI-36	3.3	2.5	2.3	1.3
	Gloria Pink	3.7	3.0	2.7	1.0
	NY-2114-12	1.5	1.0	1.3	0.2
	Av.	2.8	2.2	2.1	0.8
Cultivar means[c]	UI-36	3.2	2.6	2.2	0.4
	Gloria Pink	3.3	2.6	2.4	0.7
	NY-2114-12	1.2**[d]	1.1**	1.2**	0.2

[a]0 = no injury, 4 = severe injury.
[b]Indices for the 1 and 3% O_2 are not given because they were similar to those from the air treatment.
[c]For all four aeration treatments.
[d]Cultivar means significantly different from UI-36 (** = $P = 0.01$). Oxygen treatment means are not significantly different.

Table 3. Fresh weights of shoots and roots of three bean cultivars grown for 28 days in *Fusarium*-infested soil, as affected by aeration and growth chamber temperature treatments

Treatment	Cultivar	Shoot weights (g/cell)	Root weights (g/cell)			
			Above compact layer	Within compact layer	Below compact layer	Total
		18 C for 2 wk, then 21 C until harvest				
Air	UI-36	20.6	12.1	1.8	7.5	21.4
	Gloria Pink	20.2	15.8	1.2	4.9	22.0
	NY-2114-12	19.7	20.0	2.5	11.0	33.6
	Av.	20.2	16.0	1.9	7.8	25.7
0% O_2	UI-36	11.0	9.8	0.5	0.7	11.0
	Gloria Pink	12.2	9.8	1.0	3.6	14.4
	NY-2114-12	11.9	13.1	1.2	3.0	17.3
	Av.	11.7*[a]	10.9*	0.9	2.4	14.2
Cultivar means[b]	UI-36	15.8	11.0	1.1	4.1	16.2
	Gloria Pink	16.2	12.8	1.1	4.2	18.2
	NY-2114-12	15.8	16.6**	1.9*	7.0	25.4***
		Continuous 27 C				
Air	UI-36	23.5	14.1	2.3	10.7	27.1
	Gloria Pink	28.2	15.6	2.1	10.8	28.4
	NY-2114-12	25.2	19.4	2.8	13.4	35.5
	Av.	25.6	16.3	2.4	11.6	30.3
0% O_2	UI-36	11.9	8.8	1.0	5.0	14.8
	Gloria Pink	12.6	8.4	0.6	2.7	11.7
	NY-2114-12	12.4	11.1	0.9	3.5	15.5
	Av.	12.3**	9.4*	0.8**	3.7***	14.0**
Cultivar means[b]	UI-36	17.7	11.4	1.6	7.9	20.9
	Gloria Pink	20.4	12.0	1.3	6.7	20.0
	NY-2114-12	18.8	15.2	1.8	8.4	25.5

[a]Zero oxygen treatment mean significantly different from air, and cultivar means significantly different from UI-36 (* = $P = 0.10$, ** = $P = 0.05$, and *** = $P = 0.01$).
[b]For both aeration treatments.

Table 4. Fresh weights of shoots and roots of beans grown for 28 days in *Fusarium*-infested soil as affected by soil water potential, layer bulk density, and bean cultivar

Variable	Shoot weights (g/cell)	Root weights (g/cell)			
		Top layer	Middle layer	Bottom layer	Total
Water potential (mbar)					
−800	17.95	6.23	0.84	3.62	10.68
−150	21.57***[a]	6.85**	1.10*	3.62	11.58
Layer bulk density (g/cm^3)					
1.2	19.83	5.36	1.58	4.49	11.42
1.4	20.62	6.17	1.00***	4.87	12.04
1.55	18.86	8.09***	0.33***	1.50***	9.92*
Cultivar					
UI-36	15.91	5.00	0.72	3.54	9.26
Gloria Pink	17.44	4.80	0.61	2.87	8.28
NY-2114-12	25.97***	9.82***	1.57***	4.45**	15.85***

[a]Water potential means significantly different, layer bulk density means significantly different from 1.2 g/cm^3, or cultivar means significantly different from UI-36 (* = P=0.10, ** = P=0.05, and *** = P=0.01).

Table 5. Interaction between layer density and bean cultivar as affecting root weights above a compact soil layer at two soil water potentials[a]

Layer bulk density (g/cm^3)	Weights (g/cell) of roots above layer at two soil water potentials (mbar)					
	−150			−800		
	UI-36	Gloria Pink	NY-2114-12	UI-36	Gloria Pink	NY-2114-12
1.20	4.65	4.61	8.10	3.18	3.58	8.00
1.40	4.60	5.91	9.24	4.20	4.33	8.73
1.55	7.35	5.39	11.80	5.98	4.98	13.04

[a]Interaction significant at $P = 0.05$.

about 50% (Table 3). Thus *Fusarium* resistance was largely ineffective at both temperatures when the roots were exposed to a temporary, severe oxygen stress. Yield differences among aeration treatments were most consistent at the higher temperature regime.

Both chamber temperature and aeration treatment were major factors in water use rates (Fig. 2). At the higher temperature, the water use rate was two or more times that in the cooler chamber. Within each chamber, the water use rate was reduced by low oxygen to about one-half to one-third that with normal aeration; this effect persisted after normal aeration was resumed. Differences in water use among cultivars were usually quite small. In each chamber, interactions between cultivars and oxygen concentrations were not statistically significant, indicating that the cultivars responded similarly to poor aeration.

As in the first study, cultivar resistance largely was nullified by a period of poor soil aeration. All three cultivars, from highly susceptible UI-36 to resistant NY-2114-12, reacted about the same to oxygen stress. A period of poor aeration reduced shoot and root growth and water use rates of all cultivars regardless of temperature.

Cultivar response to soil compaction and low soil water potential. Shoot weights were significantly increased by a water potential of −150 compared with −800 mbar (Table 4). NY-2114-12 outyielded the other two cultivars, which were about equal. Layer bulk density had no effect on shoot weights, and all cultivars responded similarly to the various treatments.

Root distribution was strongly influenced by both layer density and cultivar (Table 4). Root yields in the top layer of soil increased as the middle layer became more dense and thus inhibited root growth in the lower layer. Generally, increased growth above the compact layer compensated for decreased growth below, so that layer bulk density had little effect on total root growth. NY-2114-12, however, had a much larger increase in root growth above the layer as layer density increased than did UI-36 or Gloria Pink, especially at the lower soil water potential (Table 5). Thus the root rot-resistant cultivar compensated for impeded root penetration more than the susceptible cultivars by increasing growth above the impedance when the soil was infested with *Fusarium*. Miller and Burke (7) found similar increased root growth in UI-36 beans grown in fumigated soil but not when the soil was infested with *F. solani* f. sp. *phaseoli*. Thus root rot-susceptible plants appear to lose much of the compensating ability while the resistant cultivars retain it.

As with the shoot weights, water use rates were markedly reduced by decreasing soil water potential from −150 to −800 mbar, and NY-2114-12 used much more

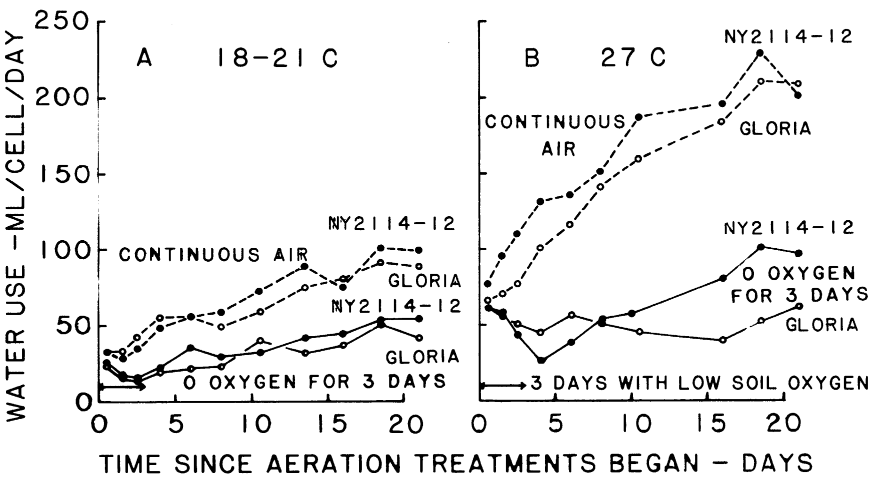

Fig. 2. Daily water use rates by two bean cultivars grown in *Fusarium*-infested soil, as affected by low soil oxygen levels for 3 days and growth chamber temperatures: **(A)** 18 C for 2 wk, then 21 C; **(B)** continuous 27 C.

water than UI-36 or Gloria Pink (data not shown).

NY-2114-12 consistently showed less root rot than Gloria Pink or UI-36. There was a significant interaction between root injury in the top soil layer and cultivar, although the differences were small. UI-36 had greater root injury at the lower potential, indicating that the cultivar least resistant to *Fusarium* may have been injured more by water stress than more resistant cultivars.

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