Effects of Low Soil Oxygen on Fusarium Root Rot of Beans with Respect to Seedling Age and Soil Temperature

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ABSTRACT

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Growth room studies determined the response of bean plants (*Phaseolus vulgaris*) growing in *Fusarium*-infested soil to temporary low soil oxygen levels as affected by seedling age and temperature. Age of seedlings (7, 12, or 19 days after transplanting) when subjected to low soil oxygen had a minor effect on shoot or root growth and water use. Temporary low soil oxygen increased injury by *Fusarium solani* f. sp. *phaseoli* regardless of seedling age. Temperature regime had a major effect on plant growth. When temperature was increased or decreased midway in the growth period, the initial temperature affected root and shoot yields more then the final one. Temporary low soil oxygen increased root rot in all temperature regimes, but the effect was usually greater at higher temperatures.

Temporary poor aeration aggravates root rot injury of beans (*Phaseolus vulgaris* L.) growing in soil infested with *Fusarium solani* (Mart.) Appel & Wr. f. sp. *phaseoli* (Burk.) Snyd. & Hans. (5,6). Increased root rot results in decreased shoot and root growth and reduced ability of roots to absorb water and to penetrate a compact soil layer.

Letey et al (3) reported that low soil oxygen availability was more detrimental to young than to older plants. Soil temperatures lower than optimum for bean growth increases Fusarium root rot (2). Beans planted in warm soil often escape the yield-depressing effects of root rot that occur when they are planted in cold soil (1). Therefore, the effects of low soil oxygen on severity of bean root rot may be directly related to plant age and temperature when poor aeration occurs. We conducted growth room studies to evaluate these factors.

MATERIALS AND METHODS

In each study, a set of 36 plant growth cells was prepared (4) with soil from a *Fusarium*-infested field of Warden loam where beans had been grown in monoculture for many years. Surface soil at a bulk density of 1.20 g/cm^3 was used for the upper 18 cm in each cell. A layer at the 14- to 18-cm depth was packed to a bulk density of either 1.20 or 1.55 g/cm^3. Subsoil (from below 30 cm deep in the same field) packed to a bulk density of 1.20 g/cm^3 was used below 18 cm. Water potential was maintained at −150 mbar. Pregerminated seedlings with roots 2–3 cm long were transplanted three to a cell as described previously (4). Red Mexican UI-36, a cultivar susceptible to Fusarium root rot, was used throughout.

Low soil oxygen was obtained by sealing the cells (5) and passing N_2 gas across the soil surfaces for 3 days; normal aeration was then resumed and continued until harvest (28 days after transplanting). The aeration status was monitored by analyzing soil air samples for N_2, O_2, and CO_2 with a gas chromatograph.

At harvest, fresh shoots and roots were weighed and roots were indexed for *Fusarium* injury on an arbitrary scale of 0 for no injury and 4 for severe injury, where the cortex of all roots had rotted. Water use rates were measured throughout the study, beginning about 5 days after transplanting (4).

Age of seedlings when poor aeration occurred. The study was set up as four replicates of a split-plot design, using subsurface layer bulk densities as main plots and age of seedlings when aeration treatment was imposed as subplots (total of 36 cells).

Low soil oxygen treatments were started 7, 12, or 19 days after transplanting the pregerminated seedlings. Room temperatures ranged from about 22 to 24 C.

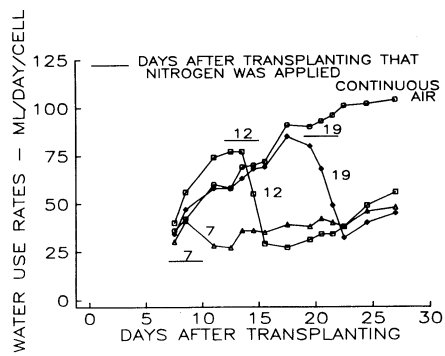

Fig. 1. Rate of water use by bean plants in *Fusarium*-infested soil as affected by 3 days of low soil oxygen beginning 7, 12, and 19 days after seedlings were transplanted.

Table 1. Fresh shoot and root weights[a] of beans as affected by soil layer bulk density and age of seedlings when subjected to low soil oxygen

Bulk density of layer[b] (g/cm^3)	Seedling age when low O_2 was applied[c]	Shoot weights (g/cell)	Roots weights (g/cell)			
			Above layer	Within layer	Below layer	Total
1.20	Mean of all treatments	16.7	4.3	0.9	3.9	9.2
1.55	Mean of all treatments	15.6 NS	5.3 NS	0.6 NS	2.8*[d]	8.7 NS
Both densities combined	Control[e]	23.2	5.4	1.1	5.4	11.9
	7 Days	13.4**	4.3	0.5*	2.0**	6.8*
	12 Days	14.6**	4.6	0.7*	3.0**	8.3*
	19 Days	13.3**	5.0	0.7*	3.0**	8.7*

[a] Fresh weights of plant shoots and roots 28 days after transplanting seedlings in soil infested by *Fusarium solani* f. sp. *phaseoli* and maintained at −150 mbar water potential.
[b] Bulk density of layer 14–18 cm deep in growth cells.
[c] Days after transplanting when roots were exposed to nitrogen gas for 3 days, which largely displaced soil oxygen.
[d] Significant differences between layer bulk density means or among seedling ages compared with air treatments (* = $P = 0.05$ and ** = $P = 0.01$). Layer bulk density × seedling age interaction not significant ($P = 0.10$).
[e] Control cells were exposed only to room air.

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Temperature when poor aeration occurred. Thirty-six cells were prepared as described before, except all cells had a compact layer (1.55 g/cm^3) at the 14- to 18-cm depth. They were divided into two groups of 18 cells each, with a group placed in each of two growth rooms. Temperature in both rooms was maintained at 27 C for 5 days, until the seedlings were well emerged. One growth room was then cooled (day 6) to 18 C while the other was continued at 27 C. The next day (day 7), poor aeration was established and continued for 3 days (through day 9), followed by normal aeration. On day 19, half of the cells in each room were switched with corresponding ones from the other room. This resulted in four temperature regimes imposed after the 5-day period for seedling establishment: 1) continuous 18 C for days 6–28; 2) 18 C for days 6–18, then increased to 27 C for days 19–28; 3) continuous 27 C for days 6–28; and 4) 27 C for days 6–18, then decreased to 18 C for days 19–28.

All cells were harvested 28 days after planting. Shoot and root weights, disease injury to roots, and water use were determined as described before. This experiment was repeated to obtain a total of eight replicates of the four temperature regimes.

RESULTS AND DISCUSSION

Layer bulk density and poor aeration. Layer bulk density did not significantly affect shoot or root weights, except roots in the bottom layer were decreased by the compact layer (Table 1). This effect was somewhat more pronounced in seedlings subjected to low oxygen 7 days after planting than in those subjected to low oxygen 12 or 19 days after planting or to continuous air. *Fusarium* injury to the hypocotyl and roots was greater with than without the compact soil layer (Table 2) although differences were small. All roots in the surface soil were moderately to severely rotted, whereas those in the subsoil were relatively healthy. These data agree with previous work showing that *Fusarium* infection combined with low soil oxygen reduces the ability of the roots to penetrate compact soil (5) and that *Fusarium* infection reduces the ability of susceptible cultivars to increase root growth above a compact layer (4).

Age of seedlings when poor aeration occurred. The age of seedlings when subjected to low soil oxygen had a minor effect on subsequent shoot or root growth, although the data show a trend for fewer roots on seedlings treated when 7 days old than on those treated when 12 or 19 days old (Table 1). Plant weights for all three ages (7, 12, 19 days) were decreased compared with those receiving continuous air.

Water use rates were greatly reduced by the low-oxygen treatment regardless

Table 2. Indices[a] of injury caused by Fusarium root rot as affected by soil layer bulk density and age of seedling when subjected to low soil oxygen levels

Bulk density of layer[b] (g/cm^3)	Seedling age when low O_2 was applied[c]	Hypocotyl	Roots		
			Above layer	Within layer	Below layer
1.20	Mean of all treatments	3.1	2.7	2.4	1.3
1.55	Mean of all treatments	3.6*[d]	3.2*	3.4**	1.4 NS
Both densities combined	Control[e]	2.5	2.2	2.2	1.0
	7 Days	3.5**	3.2**	3.1**	1.4
	12 Days	3.8**	3.5**	3.4**	1.5
	19 Days	3.5**	2.8	2.9*	1.5

[a] 0 = no injury, 4 = severe injury.
[b] Bulk density of layer 14–18 cm deep in growth cells.
[c] Days since transplanting when roots were exposed to nitrogen gas for 3 days, which largely displaced soil oxygen.
[d] Significant differences between layer bulk density means or among seedling ages compared with air treatments (* = $P = 0.05$ and ** = $P = 0.01$). Layer bulk density × seedling age interaction not significant ($P = 0.10$).
[e] Control cells were exposed only to room air.

Table 3. Effect of temperature regime and temporary low soil oxygen on weights of fresh bean shoots and roots[w]

Temperature (C)				Root weights (g/cell)			
6–18 Days	19–28 Days	Aeration treatment[x]	Shoot weights (g/cell)	Above compact layer	Within compact layer	Below compact layer	Total
18	18	Air	23.6	9.0	1.3	4.3	14.7
		N_2	18.6	8.4	0.8	1.3	10.5
		Mean	21.1 ab[y]	8.7 a	1.0 a	2.8 a	12.6 a
18	27	Air	22.4	9.4	1.4	4.0	14.8
		N_2	15.6	6.4	0.6	2.2	9.3
		Mean	19.0 a	7.9 a	1.0 a	3.1 a	12.0 a
27	27	Air	30.0	11.0	1.7	10.7	23.5
		N_2	16.7	10.5	1.1	5.7	17.4
		Mean	23.3 bc	10.8 b	1.4 b	8.2 b	20.4 b
27	18	Air	28.5	12.1	2.1	11.2	25.4
		N_2	19.2	9.6	0.9	2.2	12.8
		Mean	23.8 c	10.8 b	1.5 b	6.7 b	19.1 b
Temperatures combined		Mean air	26.1	10.4	1.6	7.6	19.6
		Mean N_2	17.5**[z]	8.7**	0.8**	2.9**	12.5**

[w] Fresh weights of plant shoots and roots 28 days after transplanting seedlings in soil infested with *Fusarium solani* f. sp. *phaseoli* and maintained at −150 mbar water potential.
[x] Seedlings were exposed to nitrogen gas from the seventh through ninth day after transplanting, which largely displaced soil oxygen, or to normal aeration.
[y] Aeration treatment means followed by the same letter were not significantly influenced by temperature regime ($P = 0.05$).
[z] ** = N_2 mean significantly less than air mean at $P = 0.01$. Temperature × aeration interaction significant for shoots at $P = 0.10$, for bottom roots at $P = 0.05$, and for total roots at $P = 0.10$. Others not significant at $P = 0.10$.

Table 4. Indices[w] of injury caused by Fusarium root rot as affected by temperature and temporary low soil oxygen

Temperature (C)		Aeration treatment[x]	Roots		
6–18 Days	19–28 Days		Above compact layer	Within compact layer	Below compact layer
18	18	Mean of both	3.25 a[y]	3.75 a	0.50 a
18	27	Mean of both	3.12 a	3.38 a	0.38 a
27	27	Mean of both	2.87 a	3.50 a	0.25 a
27	18	Mean of both	3.12 a	3.38 a	0.25 a
Temperatures combined		Mean air	2.56	3.12	0.00
		Mean N_2	3.62**[z]	3.81*	0.69**

[w] 0 = No injury, 4 = severe injury.
[x] Seedlings were exposed to nitrogen gas from the seventh through the ninth day after transplanting, which largely displaced soil oxygen, or to normal aeration.
[y] Aeration treatment means followed by the same letter were not significantly influenced by temperature regime ($P = 0.05$).
[z] N_2 mean significantly greater than air mean (* = $P = 0.05$ and ** = $P = 0.01$). Temperature × aeration interactions not significant ($P = 0.10$).

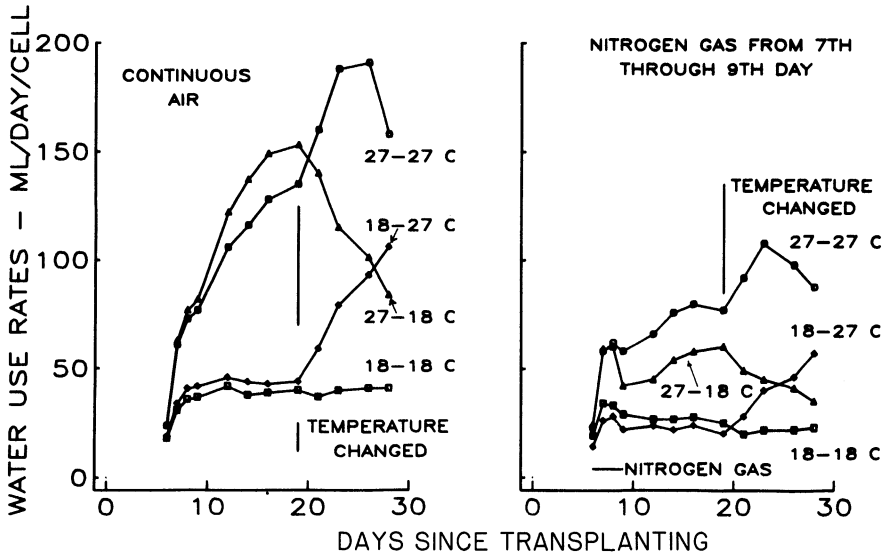

Fig. 2. Rate of water use by bean plants in *Fusarium*-infested soil as affected by low soil oxygen from the seventh through the ninth day after seedlings were transplanted and by temperature regime.

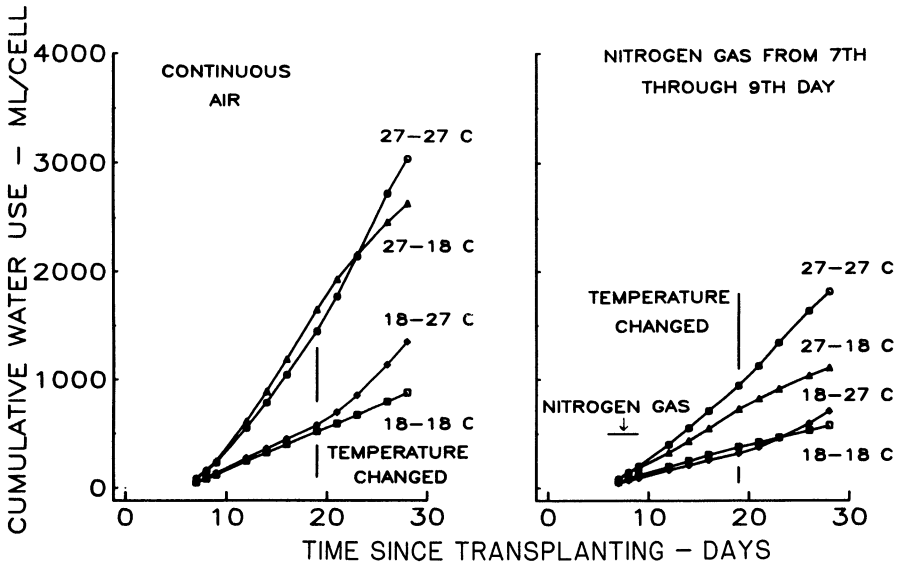

Fig. 3. Cumulative water use by bean plants in *Fusarium*-infested soil as affected by low soil oxygen from the seventh through the ninth day after seedlings were transplanted and by temperature regime.

of plant age (Fig. 1). After normal aeration was resumed, water use remained low until harvest, indicating permanent root damage. Injury to plants in this study was less than in our previously reported work (5), so some recovery from root injury occurred as indicated by the upward slope of the water use curves (Fig. 1). Nevertheless, poor aeration did greatly reduce root activity, and this only partially recovered with normal aeration.

Temperature when poor aeration occurred. Both temperature and aeration treatments had a large effect on growth. The initial temperature had more effect than the final temperature on yields of shoots and roots (Table 3). Shoot and root weights were not increased by increasing the temperature to 27 C after an initial period of 18 C compared with continuous 18 C, nor were they reduced by lowering temperature to 18 C after a period at 27 C compared with continuous 27 C. Low oxygen reduced root and shoot weights at all temperatures, but the relative effect was usually greater with the higher initial temperature.

The degree of Fusarium root rot injury was not affected by temperature (Table 4). Injury was much more severe at all temperatures with than without the period of temporary low soil oxygen.

Water use rates were markedly affected by both temporary low soil oxygen and temperature treatments (Fig. 2). The low-oxygen effect persisted until harvest, reflecting both decreased root growth (Table 3) and increased root injury (Table 4). The largest decrease in water use rates attributed to low oxygen was at the high temperature, but the percentage decrease was about the same for all temperature combinations.

Plant water use responded rapidly to the changes in temperature (imposed 19 days after transplanting), reflecting the difference in atmospheric water demand at the different temperatures (Fig. 2). This is illustrated by the water use rates at harvest, which were greater with the 18/27 C than with the 27/18 C temperature combination; the shoot and root weights were the opposite (Table 3); ie, greater with the initially high temperature.

Total water use within an aeration treatment was dominated by the initial temperature (Fig. 3). The lowest total water use was at a continuous temperature of 18 C with temporary low soil oxygen, whereas the highest was at 27 C with adequate aeration. Although daily water use responded rapidly to temperature change, the plant growth response to the initial 6- to 18-day temperature was sufficient to minimize the effect of the final 9-day temperature.

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