

Effect of Soil Aeration on *Fusarium* Root Rot of Beans

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ABSTRACT

When the oxygen supply to 4-week-old bean seedling roots was reduced for 24, 48, or 72 hours in soil infested with *Fusarium solani* f. sp. *phaseoli*, root and top yields were reduced. Furthermore, root penetration of a compacted subsurface soil layer was reduced by the temporary poor aeration. In contrast, in fumigated, pathogen-free soil, the

same aeration treatments did not effect plant top and root growth. When plants were exposed for 2 days to a soil-atmosphere mixture of 10% O₂, 10% CO₂, and 80% N₂ in *Fusarium*-infested soil, greater plant growth resulted than with air.

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

We have observed that excessive wetting of the soil from furrow irrigation decreases yields of dry beans (*Phaseolus vulgaris* L.) and that the reduction is much

greater in soil infested with the root-rot pathogen *Fusarium solani* (Mart.) Appel and Wr. f. sp. *phaseoli* (Burk.) Snyder and Hans. than in noninfested soil.

Possible reasons for the yield reduction are aggravation of root rot by temporary poor aeration (10), lowered soil temperatures (2), or increased soil bulk density (3, 8), resulting from excessive wetting.

Stolzy and Letey (9) showed that many plant roots did not grow well with low oxygen diffusion rates (ODR) of about 0.15 to 0.20 $\mu\text{g cm}^{-2} \text{min}^{-1}$. Wet soil is associated with low ODR values (1, 4, 6). Erickson and Van Doren (5) reported that recovery of adequate ODR after irrigation may take several days, and emphasized that short periods of poor aeration can be detrimental to plants. Letey, et al. (7) reported that periods of low oxygen supply were more detrimental to young plants than to plants with larger root systems. When subjected to low oxygen supply, roots stopped growing and did not recover immediately when adequate aeration was resumed. Stolzy, et al. (10) found that soil aeration and root injury by a pathogen were related. They observed that citrus roots attacked by *Phytophthora* spp. in wet soil recovered poorly because of insufficient oxygen for root growth.

Because temporary poor aeration could explain the observed yield reductions of beans in *Fusarium*-infested soil, we studied in the laboratory the effects of soil aeration on bean root injury by *F. solani* f. sp. *phaseoli*.

MATERIALS AND METHODS.—*Soil air composition.*—Warden loam soil was packed in slabs (8) 1.5 cm thick, 32 cm high and 17 cm wide. Each slab was placed in a cell consisting of two plates, one of which was the porous ceramic side of a suction chamber. This chamber was water-filled and connected to a water supply under controlled vacuum, which maintained the soil water potential nearly constant at about -150 millibars. Three soil layers in each slab simulated field seedbed conditions (3): an upper 14-cm layer of surface soil packed to a bulk density of 1.2 g/cm³; a middle 4-cm layer of surface soil packed to 1.55 g/cm³; and a bottom 14-cm layer of subsoil packed to 1.2 g/cm³. Cells were packed with soil from a field infested by *Fusarium solani* f. sp.

TABLE 1. Composition of soil air at depths of 8, 17, and 24 cm 1 day after initiation of aeration treatments

| Soil Depth (cm) | Aeration treatment | | | |
|-----------------|--------------------|-----------------------|---------|---------|
| | Air | 10-10-80 ^a | 0-20-80 | 0-0-100 |
| | % CO ₂ | | | |
| 8 | 0.3 ^b | 9.9 | 18.5 | 0.4 |
| 17 | 0.4 | 9.5 | 15.6 | 0.3 |
| 24 | 0.4 | 9.2 | 13.6 | 0.4 |
| | % O ₂ | | | |
| 8 | 20.6 | 11.6 | 2.3 | 0.9 |
| 17 | 20.5 | 11.8 | 3.4 | 1.4 |
| 24 | 20.4 | 12.2 | 5.0 | 2.7 |

^aFigures indicate percentages of O₂, CO₂, and N₂, respectively.

^bEach value is the average of measurements from four plant-growing cells each with three Red Mexican bean plants; two containing *Fusarium solani* f. sp. *phaseoli*-infested soil and two fumigated soil.

TABLE 2. Composition of soil air at depths of 8, 17, and 24 cm 2 days after 3-day aeration treatments

| Soil Depth (cm) | Aeration treatment | | | |
|-----------------|--------------------|-----------------------|---------|---------|
| | Air | 10-10-80 ^a | 0-20-80 | 0-0-100 |
| | % CO ₂ | | | |
| 8 | 0.4 ^b | 0.6 | 0.6 | 0.4 |
| 17 | 0.6 | 0.8 | 0.9 | 0.4 |
| 24 | 0.5 | 1.0 | 1.0 | 0.4 |
| | % O ₂ | | | |
| 8 | 20.5 | 20.5 | 20.4 | 20.6 |
| 17 | 20.3 | 20.2 | 20.3 | 20.4 |
| 24 | 20.3 | 20.2 | 20.3 | 20.4 |

^aFigures indicate percentages of O₂, CO₂, and N₂, respectively.

^bEach value is the average of measurements from four plant-growing cells each with three Red Mexican bean plants; two contained *Fusarium solani* f. sp. *phaseoli*-infested soil and two fumigated soil.

phaseoli or with the same soil fumigated with methyl bromide. In addition, two cells were prepared with fumigated soil reinoculated with a pure culture of *F. solani* f. sp. *phaseoli* to test the effects of aeration on bean plants exposed to the *Fusarium* alone as compared with those exposed to other microorganisms in the nonfumigated soil.

Three bean seedlings (Red Mexican CV UI 36) were planted in each cell and covered with 1 cm of sand. The cells were lighted with fluorescent lamps and held at room temperatures which ranged from about 22 to 24 C. The study was arranged in three replications of a split-plot design with four aeration treatments as main plots and either *Fusarium*-infested or fumigated soil as subplots.

The surface of the sand covering the soil was about 0.5 cm below the top of the cell. Five days after seedlings emerged, the top of the cell was sealed with plastic tape and paraffin, leaving an air-filled space above the sand surface and soil aeration treatments were started. Soil aeration was varied by passing the desired gas mixtures over the sand surface with diffusion of the gas mixtures into the soil. Cells subjected to normal aeration were left open to the atmosphere. Gas sampling ports were placed in the edge of each cell of two replications at 8-, 17-, and 24-cm depths (above, within, and below the compact layer, respectively). During the treatment and periodically afterwards, soil atmosphere composition was monitored by using a gas chromatograph and 0.5-ml air samples. The aeration treatments were: (i) ambient air with cell unsealed; (ii) a mixture of about 10% O₂, 10% CO₂, and 80% N₂ (10-10-80), with O₂ and CO₂ ranging from about 9 to 11% during treatment; (iii) a mixture of about 20% CO₂ and 80% N₂ (0-20-80) with CO₂ ranging from about 20 to 21% during treatment; and (iv) pure N₂ (0-0-100).

The mixtures were obtained by bubbling compressed gases (CO₂, N₂, and air) at controlled pressure through needle valves and through water columns, into manifolds, from which the mixtures were distributed to the

respective cells. After the desired compositions were obtained by trial and error they remained nearly constant.

After 3 days of aeration, the surface seals were opened to the atmosphere. The plants were harvested 4 weeks after planting and green top weights and fresh root weights above, within and below the compacted soil layers were determined.

Each unit was equipped with a calibrated water supply flask. Daily and cumulative rates of water use were measured from 1 day before aeration treatments were applied until plant harvest.

Duration of aeration variables.—After completing the described 3-day aeration study, we conducted another study to evaluate the influence of duration of aeration treatment on injury from the *Fusarium*. Cells were prepared as before, using *Fusarium*-infested field soil. Six days after plant emergence, soil was aerated for 1, 2, or 3 days with the same soil atmosphere composition treatments as used previously. Root and top yields and water-use rates were measured. Cells were also prepared with the fumigated soil reinoculated with *Fusarium*, and subjected for 3 days to treatments 0-20-80 and 0-0-100. All treatments were replicated three times.

RESULTS.—**Soil air composition.**—Soil atmosphere compositions, measured 1 day after the aeration treatments were started, are shown in Table 1. Soil atmosphere compositions changed little during the remainder of the treatment period, except that CO₂ increased about 2% at the 17- and 24-cm depths in treatment 0-20-80. Air exchange between the soil and applied gas mixture was rapid, and, within a few hours, the upper soil section was near equilibrium.

Soil atmosphere composition 2 days after the aeration treatments were stopped is shown in Table 2. For the remainder of the experiment, CO₂ in the fumigated soil gradually increased until, at harvest time, it ranged from about 1 to 2%. In the *Fusarium*-infested soil, CO₂ levels remained about 0.5% (data not shown).

Plant top and root weights.—In fumigated soil, top and root growth were affected little by the 3-day aeration treatments (Fig. 1 and 2). In the infested soil, however, top and root yields decreased as oxygen decreased, with the lowest yields from treatment 0-0-100. Plants receiving treatment 0-0-100 were severely injured, and growth had almost stopped until near harvest. For each treatment, the relationship between soil aeration and *Fusarium* infection in causing plant injury can be expressed by the plant weights in the infested soil as a percentage of the plant weights in the fumigated soil. These values are 39, 26, 19, and 6% for the air, 10-10-80, 0-20-80, and 0-0-100 (O₂-CO₂-N₂) treatments, respectively (Fig. 2-A).

In the fumigated soil, the weight of roots which penetrated the compacted layer was influenced only slightly by the aeration treatments (Fig. 2-C). When aeration was good, root weights below the compact layer were about the same in the fumigated and nonfumigated soils. However, when oxygen was reduced, the ability of the roots to penetrate the compact layer in the infested soil decreased. In the 0-20-80 and 0-0-100 treatments, hardly any roots penetrated the compacted layer.

Water-use rates.—Like plant growth, water-use rates were influenced relatively little by the aeration treatments in the fumigated soil, but were markedly affected in

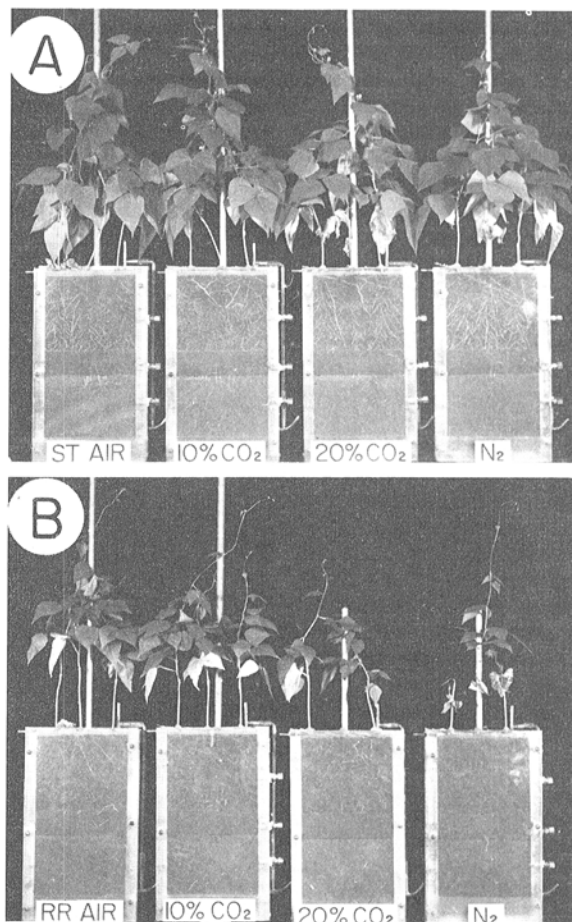


Fig. 1-(A, B). Top growth of four-week-old bean plants as affected by aeration treatment in A) fumigated soil, and B) *Fusarium*-infested soil. The 10% CO₂ treatment consisted of 10% CO₂, 10% O₂, and 80% N₂. The 20% CO₂ treatment consisted of 20% CO₂ and 80% N₂.

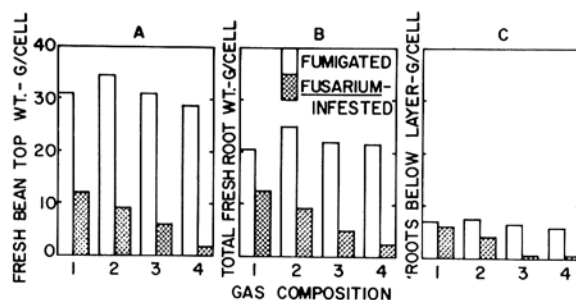


Fig. 2-(A to C). Effect of 3-day treatments of bean roots with various gas compositions on A) fresh top weights, B) fresh root weights, and C) roots penetrating a compact subsurface layer. Plants were 4 weeks old. Treatment 1 - room air; 2 - 10% O₂, 10% CO₂, 80% N₂; 3 - 20% CO₂, 80% N₂; and 4 - 100% N₂.

Fusarium-infested soil (Fig. 3). Water-use rates in fumigated and infested soil exposed only to air were similar for about 2 weeks, then, in the infested soil, they declined with time. The 10-10-80 treatment in the infested

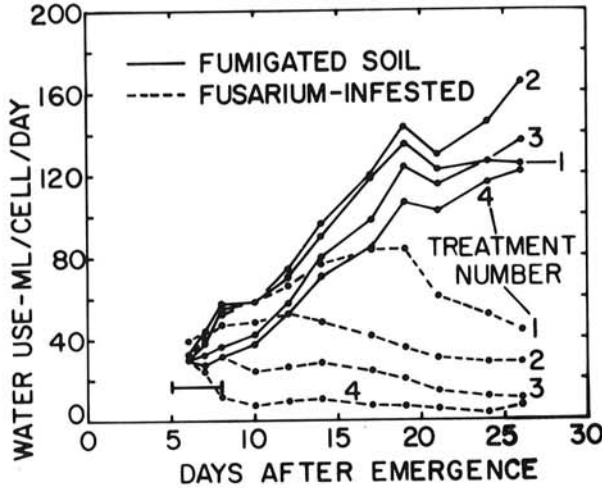


Fig. 3. Effect of *Fusarium* infestation and soil air composition on water-use rates by bean plants. Air variables were applied from the 5th to the 8th day after emergence (indicated by \perp — \perp). Treatment 1 - room air; 2 - 10% O₂, 10% CO₂, 80% N₂; 3 - 20% CO₂, 80% N₂; and 4 - 100% N₂.

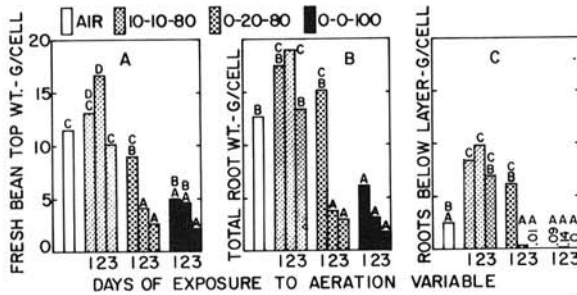


Fig. 4-(A to C). Effect of duration of exposure of bean roots in *Fusarium*-infested soil on A) fresh top weights, B) fresh root weights, and C) roots penetrating a compact subsurface layer. Bars labelled with the same letter are not significantly different, $P = 0.05$. Treatment legends indicate percentages of O₂, CO₂, and N₂, respectively.

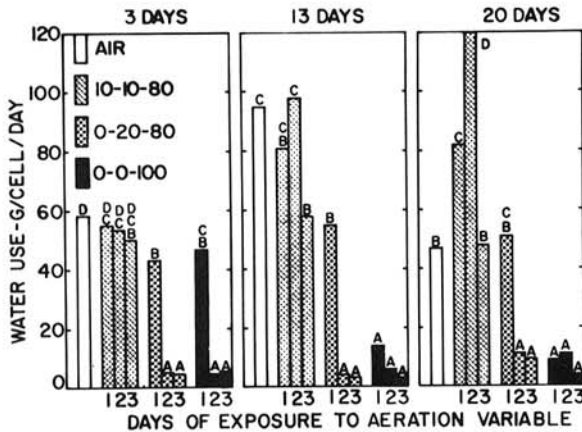


Fig. 5. Effect of duration of exposure of bean roots in *Fusarium*-infested soil on water use rates 3, 13, and 20 days after treatments began. Bars within a given day with the same letter are not significantly different, $P = 0.05$. Treatment legends indicate percentages of O₂, CO₂, and N₂, respectively.

soil resulted in a sharp decline in water-use rates about a week earlier than in the well-aerated soil. When the infested soil received no oxygen in the treatment gas (0-20-80 or 0-0-100), water-use rates remained low throughout the experiment. The rate of decline in water use decreased near harvest as some plant recovery occurred and a few new leaves developed.

Effect of duration of aeration variables.—Duration of exposure to the various gas treatments had a marked effect on root injury (Fig. 4). Yields of tops and roots decreased as exposure time increased for both the 0-20-80 or 0-0-100 treatments; and, as before, the effect of N₂ alone (0-0-100) was greater than that of 20% CO₂ + 80% N₂ (0-20-80).

Compared with the control (air), 1 or 2 days of exposure to the 10-10-80 mixture stimulated some plant growth, as indicated by the water-use data in Fig. 5. When aeration was stopped (at 3 days), differences among the control and the three exposure times for 10-10-80 were not significant. Ten days later, water-use rates in the cells treated for 3 days were less than those of the control. After another week, water-use rates for the control had markedly decreased, while rates for 1 or 2 days under 10-10-80 were significantly greater. Water-use rates were also greater with 0-20-80 than with 0-0-100 in 1-day treatments.

In both experiments, the effect of the aeration variables were similar for the *Fusarium*-infested field soil and the fumigated soil reinoculated with a pure culture of *F. solani* f. sp. *phaseoli*.

DISCUSSION.—This study shows that short periods of poor aeration markedly influence bean growth in *Fusarium*-infested soil and aggravate the injury caused by *Fusarium* infection. In addition, poor aeration reduces the ability of infected roots to penetrate a compact soil layer. Inasmuch as injury was usually greater with 0-0-100 than with 0-20-80, it seems probable that the injurious results of poor aeration are due to low O₂ rather than to high CO₂.

Root-rot injury was reduced by the 10-10-80 treatment applied for 1 or 2 days. Possibly the CO₂ or reduced O₂ sufficiently suppressed *Fusarium* activity to allow plants to overcome some of the direct detrimental effects of the treatment. Three days of exposure to this mixture reduced yields to about the control values and significantly below those obtained with 2 days of exposure.

Inasmuch as similar results were obtained with the *Fusarium*-infested field soil and the fumigated, reinoculated soil, we concluded that the root deterioration resulting from the various treatments is related principally to the presence of *F. solani* f. sp. *phaseoli* in the field soil rather than to treatment interactions with other soil microflora. However, further studies would be necessary to determine whether other pathogens, such as *Pythium ultimum* and *Rhizoctonia solani*, present in the infested field soil, might also interact with the aeration variables.

Soil-atmosphere compositions as low in O₂ and high in CO₂ as used here may not occur in the field under furrow irrigation. However, oxygen diffusion rates to the root surface are very low in wet soil, and it is probable that low diffusion rates occur after furrow irrigation, especially during the first irrigation of the season when infiltration

rates are high and the soil wets rapidly. Low diffusion rates would affect plants similarly to low O₂ contents in the soil atmosphere in that the roots would not receive adequate O₂. The decreased bean yields resulting from excess wetting, in *Fusarium*-infested soil, are probably due to a temporary oxygen deficit at the root surface which restricts root growth. The plant becomes more susceptible to root-rot injury (1, 2) and subsequent recovery is slow.

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