Control of Fusarium Root Rot with Bean Residues

Fusarium root rot of beans (Phaseolus vulgaris L.), caused by Fusarium solani (Mart.) Appel & Wr. f. sp. phaseoli (Burk.) Snyder & Hors., probably occurs to some degree in most bean fields throughout the world. The disease usually causes little damage if the plants are not stressed by other environmental factors that restrict root growth. The most obvious symptom is red to brown streaking or general necrosis of the taproot and hypocotyl cortex.

Fusarium root rot can be much more serious than the “foot rot” it is often considered to be. The most damaging effects are in the rotting that reduces the efficiency of the entire root system (3). The microbial ecology and behavior of the pathogen in the soil have been largely explained by W. C. Snyder and his students and co-workers through detailed studies at the University of California, Berkeley, during the past three decades (9). This article is based principally on research during the past two decades at the Irrigated Agriculture Research and Extension Center in Prosser, Washington, on the ecology and control of the disease through soil and water management and development of resistant beans.

Etio logical and Ecologic Premises

Beans planted in cold, Fusarium-infested soil or subjected to cool weather after emergence tend to have severe root rot, whereas those planted and raised in warm soil with adequate water tend to escape serious root rot. In cold soil, root growth is restricted and plants suffer physiological drought. Also, herbicides and decomposing organic matter may be toxicogenic in cold soil and aggravate the root rot problem (14).

Surface soil compaction by tractor wheels (Fig. 1) and subsurface tillage pans (7) are among the most noticeable root-restraining, disease-preconditioning problems involved in bean root rot. Hard subsurface soil layers caused by discs, rotary tillers, and other implements used during the past two decades to incorporate herbicides could well be responsible for the near static to declining average yields of beans in the United States, despite substantial concurrent genetic improvement of beans with regard to important disease resistance and other qualities.

The most frequently occurring predisposing stress is intermittent drought, especially in coarse-textured soils of low water-holding capacity and where soil compaction may confine the roots to a small volume (2). In irrigated sandy loam soils infested with F. solani f. sp. phaseoli, variations in soil compaction and water distribution can cause up to 10-fold variations in seed yields within the same field. Drought during flower and pod development is especially serious, because it not only predisposes plants to severe root rot but also more directly restricts flower, pod, and seed development.

Another acutely aggravating contributor to Fusarium root rot is excess soil water, which, even for short periods during irrigations, reduces oxygen diffusion to roots and thus retards root growth. Temporary retardation of root growth leads to severe Fusarium root rot and permanently restricted plant growth (10) (Fig. 3). Such oxygen stress has been found to completely nullify the best known sources of resistance to the bean Fusarium and even to make bean roots susceptible to attack by the pea pathogen, F. solani f. sp. pisi (11). Bean plants in soil with no pathogenic Fusarium, even if the soil is infested with other pathogens such as Pythium ultimum, Rhi zoctonia solani, and Thielaviopsis basicola, largely recover from brief periods of poor root aeration.

Good soil fertility is important for maximizing bean yields, whether or not root rot is a problem, but fertilization appears to have little if any effect on Fusarium root rot. Form and quantity of nitrogen have been reported to influence the disease in controlled experiments, but in the field, such influences are ephemeral and apparently unimportant, having little effect on disease severity.

Rotation of beans with such crops as small grains and alfalfa, which add large amounts of root and top residues to the soil, usually tends to counteract root rot by reducing soil compaction and increasing water-holding capacity of the soil. Decaying alfalfa roots provide channels for deep penetration of the soil by bean roots. If incorporated in the soil at least a month before planting, alternate crop residues may also reduce root rot through a salutary effect on Fusarium-suppressive soil microflora. Sometimes, however, especially in cold, wet soil, recently incorporated, nondecomposed organic matter from almost any previous crop becomes toxic to bean plants and increases root rot (14). In Fusarium-
Resistant Beans and Cultural Management

infested fields, close spacing of plants tends to increase "foot rot" symptoms of the disease, but plant populations providing the most nearly complete ground cover produce the highest seed yields.

The supposed interaction of the seedling pathogens *Pythium*, *Rhizoctonia*, and *Thielaviopsis* in Fusarium root rot of beans has yet to be demonstrated except in greenhouse experiments, which seldom, if ever, correlate with field events in bean root rot. On the contrary, a recent 3-year field study (6) indicated that forms of *F. solani* attacking beans and peas were predominant and almost independent in causing significant root rots of these two crops in irrigated sandy loam soils, even when pathogens in the other three genera were obviously attacking the seedlings.

*F. solani* l. sp. *phaseoli*, unlike *Pythium* and *Rhizoctonia*, seldom causes serious damage to emerging bean seedlings. Usually, *Fusarium* colonizes the belowground parts of the seedling as they contact its germinable resting chlamydomycetes in the soil and remains an opportunistic pathogen throughout the life of the plant. *T. basicola* colonizes belowground parts of most bean plants and may cause considerable black cortical necrosis without seriously harming the plants. In some soils that are constantly wet, especially during the first half of the growing season, *Aphanomyces* or *Pythium* pathogens may predominate, or in soils high in previous-crop residues near the soil surface, *R. solani* may predominate, even though *F. solani* l. sp. *phaseoli* is present and infecting the roots.

Studies in Wisconsin soils seem to relegate large populations of pathogenic *F. solani* to minor roles in root rots of beans (12) and peas (5). In the usually moist soils of that state, *A. euteiches* may be the main yield-reducing pathogen in both beans and peas. *Fusarium* may become important only if drought occurs and if *Aphanomyces* has not already invaded the roots.

**Direct Control Measures**

Numerous efforts in direct control of *Fusarium* root rot have failed because treatments have been directed at reduction of localized "foot rot" symptoms on the hypocotyl and taproot. Rarely, if ever, have such treatments improved bean yields. In 1966 (3), we found that the effect of root rot on yields of beans in *Fusarium*-infested fields was not reduced even by complete protection of hypocotyls and taproots in "islands" of pathogen-free soil from which most of the root system extended into *Fusarium*-infested soil. Conversely, in another field where the root systems extended from *Fusarium*-infested islands into soil free from the pathogenic *Fusarium*, bean yields were equal to those of plants in the same field whose hypocotyls and taproots were not exposed to *Fusarium*. Vigorous, unrestricted roots outgrew and overcame local hypocotyl and taproot infections (Fig. 4).

*Fusarium* root rot of beans, like *Aphanomyces* root rot of peas (4), apparently affects most, if not all, of the root system when it significantly depresses yields. Control of such diseases by seed treatment or other localized treatments is impossible unless the treatments are capable of protective systemic or surface movement to the root systems. Nevertheless, localized treatments that control seed rot and seedling damping-off help ensure optimal plant populations, which in turn may help counteract yield depressions by root rot.

**Development of Resistant Beans**

Thus far, complete genetic resistance or immunity to *F. solani* l. sp. *phaseoli* has not been discovered in *P. vulgaris*. Furthermore, available genotypes with highest levels of resistance, as measured by degree of hypocotyl and root necrosis (15), are late-maturing and have not been

---

Fig. 2. Effect of soil water potential and infestation by *Fusarium solani* l. sp. *phaseoli* on growth of bean roots through compact soil. Soil was held at (left) -200 mb matric potential (sufficient water) and (right) -800 mb matric potential (moderate water stress). Marker indicates location of soil layer with bulk density of 1.55 g/cm²; distance between marks is 4 cm. (From Miller and Burke. 1974. Phytopathology 64:526-529.)

Fig. 3. Beans in *Fusarium*-infested sandy loam soil saturated with water, as in an earlier irrigation. Soil saturation restricts oxygen diffusion to roots, retarding their growth and predisposing them to *Fusarium* rot.

Fig. 4. Bean plants grown in a noninfested field in "islands" of soil infested by *Fusarium solani* l. sp. *phaseoli*. (Left) Roots grew unrestricted; (right) roots were enclosed in a clay pot, but a vigorous one escaped through a hole in the bottom of the pot. (From Burke. 1968. Phytopathology 58:1675-1676.)

General soil fumigation with such chemicals as chloropicrin and methyl bromide will usually control *Fusarium* root rot.
Table 1. Seed yields of bean cultivars differing in root rot susceptibility in adjacent Fusarium-infested and noninfested fields

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Noninfested field (kg/ha)</th>
<th>Fusarium-infested field (kg/ha)</th>
<th>Yield reduction due to root rot (kg/ha)</th>
<th>(%)</th>
<th>Disease index *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Mexican UI-36</td>
<td>4.038</td>
<td>1.901</td>
<td>2.137</td>
<td>52</td>
<td>62</td>
</tr>
<tr>
<td>Columbia pinto</td>
<td>3.456</td>
<td>2.209</td>
<td>1.247</td>
<td>36</td>
<td>61</td>
</tr>
<tr>
<td>Red Mexican Big</td>
<td>3.524</td>
<td>2.622</td>
<td>0.902</td>
<td>25</td>
<td>76</td>
</tr>
<tr>
<td>Pinto UI-114</td>
<td>3.684</td>
<td>2.889</td>
<td>0.889</td>
<td>21</td>
<td>49</td>
</tr>
<tr>
<td>Red Mexican OR-S</td>
<td>3.459</td>
<td>2.905</td>
<td>0.554</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>Sutter Pink</td>
<td>3.087</td>
<td>2.884</td>
<td>0.203</td>
<td>5</td>
<td>43</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>385 kg</td>
<td>312 kg</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Average data from 20 replications of plots consisting of four 56 cm x 10 m rows in each field. Fertility, irrigation, and tillage were about the same in each field.

* Arbitrary ratings of root and hypocotyl necrosis 7 weeks after plant emergence: 25 = slight, 50 = moderate, 75 = severe, and 100 = very severe. Data are means of root evaluations made in 20-lm sections of rows of each cultivar in the Fusarium-infested field. Root necrosis was negligible in the noninfested field.

A selection from the cross Red Mexican UI-35 X PI 203958 for resistance to Fusarium solani f. sp. phaseoli.

In 1967 we discovered in field tests that the early-maturing short-vine cultivar Sutter Pink has an effective Fusarium resistance as measured by both severity of root necrosis and seed yield under root rot stress (Table 1). The high-quality cultivars Idaho Pinto UI-114 and Black Turtle Soup (8) were also found to be less sensitive than most cultivars to yield reduction by root rot. Resistance to Pythium species, R. solani, and seedcorn maggot (8) is found mainly in certain pink and black, as well as brown and yellow, beans. Beebe et al. (1) and Boomstra et al. (2) recently reported a number of additional sources of resistance to F. solani f. sp. phaseoli that remain to be thoroughly studied and utilized as parents. The senior author, in 1967, tested a wild bean selection sent by O. Norvell and identified as P. griseus. This bean appeared to be immune to Fusarium in greenhouse tests. Norvell (personal communication) indicated that the bean was compatible in crosses with P. vulgaris, but, unfortunately, the seed source was lost and tests were never completed.

Recently, D. J. Hagedorn and R. E. Rand of the University of Wisconsin, Madison, released four snap bean breeding lines, Wisc. (RRR) 77, 83, 46, and 36, resistant to Fusarium, Pythium species, Rhiococtonia, and Aphanomyces. In 1983, A. H. Dickson of New York State University, Geneva, released three snap bean breeding lines, GRR 1869, 1819, and 1913, tolerant of Pythium and Fusarium. G. J. Kolar of the University of Idaho, Moscow, released the great northern cultivar UI-60, productive under Fusarium root rot stress.

During the past 20 years, our project has cooperated in development of 12 cultivars, including pink, Red Mexican, and pinto beans, with economically effective levels of Fusarium resistance. All but one of these beans include in their parentage PI 203958, the first recognized source of substantial Fusarium resistance, which originated with O. Norvell (15). All but three of the 12 cultivars also have Sutter Pink as a parent. Those consistently performing best under root rot stress are more like Sutter Pink than like the late-maturing pinto PI 203958. Unexpectedly, one of the new early-maturing short-vine cultivars with the most field resistance to root rot is Pinto NW-410, a selection from a single cross between Sutter Pink and Pinto UI-114. Table 2 compares yield of some new Fusarium-resistant cultivars with yields of older, susceptible cultivars when grown under different levels of stress in Fusarium-infested fields. The economic yield value of the partial resistance to Fusarium root rot in
the new cultivars is obviously significant.

Concurrently with the development of colored beans, we have utilized *Fusarium*-resistant pink, pinto, and Black Turtle derivatives to establish *Fusarium* resistance in white, great northern, navy, and other small white bean breeding lines.

In developing beans resistant to root rot, we select 2-week-old seedlings from among segregating populations inoculated with pure cultures of *F. solani* f. sp. *phaseoli* in greenhouse tests. These selections are transplanted and grown to maturity in the greenhouse to produce seeds for a field test. Frequently, selections for resistance to *Fusarium* cultures fail to show field resistance and vice versa. Because *Fusarium* root rot in the field is severe only under various stress conditions, greenhouse selections are tested in *Fusarium*-infested fields. They are planted early in the spring (for cold soil exposure) in compacted seedbeds and are subjected to repeated water stress between irrigations. Early-maturing short-plant types outyielding commercial cultivars under these stresses are tested further under favorable field conditions. Those producing highest yields of good-quality seeds under all conditions are retained as candidates for further evaluation.

With this kind of testing and selection, genotypes have been developed with not only *Fusarium* resistance but also cold and drought tolerance. For instance, the pink bean cultivar Roza and Pinto NW-410 have better vigor and yielding ability after exposure in early growth to cold soil and later to drought than most other beans with which they have been compared (Table 2). The pink bean cultivars Roza and Viva yield well under dryland conditions in Colorado (D. R. Wood, personal communication). Other cultivars selected in the same process, Rufus Red Mexican and the pintos NW-590, Pindak, and Holberg, are highly productive under a wide range of conditions. The combination of *Fusarium* resistance and environmental stress tolerance tends to make these beans less variable in performance than other cultivars.

Yields of five bean cultivars under high and low water stress during 6 years in *Fusarium*-infested fields are shown in Figure 5. Plots of root rot-sensitive Red Mexican UI-36 and Pinto UI-114 nearest the source of irrigation water yielded twice as much as those farthest from the source. Cultivars resistant to *Fusarium* root rot were proportionally less variable. We have found yield under stress to be the only satisfactory measure of *Fusarium*-resistance in the field. By this method, progress in development of root rot-resistant lines of preferred plant types is more rapid than with the largely futile method of selection on the basis of root disease ratings only.

### Cultural Management

We investigated various cultural methods of counteracting bean root rot by reducing environmental stresses. The most effective methods thus far have been use of the previously mentioned rotations, planting in warm soil, maintaining optimum soil water, and loosening compacted soil in the last tillage before planting (7). Loosening the soil has been the most dependable method. Subsoiler chisels (Fig. 6A) ripped the soil to a depth of 45-50 cm, either near the planter path or halfway between rows spaced 55 cm apart, in alternate interrow spaces (Fig. 6B). Irrigation furrows could be applied only in the interrow spaces, which were not chiseled. Subsoiling loosened

<table>
<thead>
<tr>
<th>Table 2. Effects of field conditions on seed yields of bean cultivars differing in sensitivity to <em>Fusarium</em> root rot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cultivar</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Red Mexican UI-36 (S)</td>
</tr>
<tr>
<td>NW-63 (R)</td>
</tr>
<tr>
<td>Pinto UI-114 (S)</td>
</tr>
<tr>
<td>NW-410 (R)</td>
</tr>
<tr>
<td>Pink Roza (R)</td>
</tr>
<tr>
<td>Best selection (R)</td>
</tr>
</tbody>
</table>

*Water stress between irrigations and stresses caused by cold soil after planting, soil compaction, and heat during blossom and pod set; mean yields from three replicate 1/740-ha plots from each of 7 years' experiments.*

*Less water and weather stress; mean yields from three replicate 1/740-ha plots from each of 3 years' experiments.*

*Beans in 2-year rotation with wheat; data from each of 5-8 years' experiments.*

*S = susceptible, R = measurable level of resistance to root and hypocotyl necrosis.*

*Number of experiments represented by mean.*

*Highest yielding selection in each yield trial and usually highest yielding among all beans tested under root rot stress each season.*

Fig. 5. Average bean seed yields from highest- and lowest-yielding plots of five cultivars grown in 12 experiments during 6 years in *Fusarium*-infested soil. Fields were irrigated in ditches between bean rows. Yields were highest at low water stress (nearest the water source) and lowest at high water stress (farthest from the water source).
compacted soil, including the plow sole, and permitted roots to extend down a meter or more. Roots in unchiseled plots were confined to the plowed layer or, in many instances, to the 10–12 cm underlaid by a “tilage pan” created by discs or other implements used to incorporate herbicides (Fig. 7A). Such treatments to loosen the soil largely counteracted the effects of Fusarium root rot on bean yields (7).

More recently, for practical purposes, smaller chisels attached to a tool bar on the planting tractor (Fig. 6C) have been used. These chisels, offset 2.5–3.5 cm from each planter path, rip the soil to a depth of 25–28 cm, thus breaking at least the compact layer created by herbicide incorporation. This tillage allows comparatively deep rooting (Fig. 7B), reduces water stress (Fig. 8), and thus, in conjunction with use of Fusarium-resistant cultivars, largely counteracts Fusarium root rot.

Ripping the soil has less effect on seed yields in noninfested than in Fusarium-infested fields (Fig. 9). Deep rooting promoted by ripping to loosen the soils should permit extension of irrigation intervals. With less frequent irrigations, incidence of Sclerotinia wilt can also be significantly reduced in areas with little summer rain.

Silbernagel (13) recently found that subsoiling to promote deeper rooting of bush-type snap beans largely controlled
Fusarium root rot in sandy loam soil. With the deep rooting and reduced row spacing, he obtained increased yields with half the usual number of irrigations.

The value of subsoiling before seeded preparation is usually nullified by later tillage, and subsoiling after plant emergence has sometimes reduced bean yields because of mechanical damage to roots. Also, subsoiling after emergence tends to push bean rows out of line, making later cultivation difficult. In fine-textured soils of high moisture-holding capacity, hilling up the soil around the plant stems promotes development of adventitious roots on the hypocotyl and thus also helps counteract effects of root rot.

In general, Fusarium-resistant beans tolerate cold soils, drought, and soil compaction better than susceptible ones in Fusarium-infested soil. Flooding, however, tends to nullify resistance to *Fusarium solani* f. sp. *phaseoli*. Beans tolerant of each of these stress factors have been reported. Several breeding programs in the United States and abroad are establishing one or more of these tolerances in *P. vulgaris*. Improved tolerance to any of these stress factors, especially when combined with *Fusarium* resistance, should contribute to the control of Fusarium root rot.

**Literature Cited**


