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# The Influence of Rotation Crops on Take-All Decline Phenomenon

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## ABSTRACT

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An irrigated site at Lind, WA, was planted 7 yr consecutively to winter wheat, divided into three replications of five rotation (break) crops for 3 yr, and finally in the 11th yr all to wheat again, to determine the influence of rotation crops on the take-all decline phenomenon. The five rotation crops included potatoes, oats, alfalfa, beans (common beans the first yr and soybeans the second and third yr), and a mixture of intermediate wheat grass and smooth brome. A given crop was in the same main plot each of the 3 yr. Spring wheat was grown in a main plot in each replicate each year as a control. Before the entire experimental area was planted to wheat in the 11th yr, each main plot was divided further into quadrants (subplots) and treated as follows: (i) only natural inoculum of the take-all pathogen, *Gaeumannomyces graminis* var. *tritici*, with no treatment; (ii) fumigated (methyl bromide); (iii) fumigated then reinfested with inoculum of *G. graminis* var. *tritici*; and (iv) not fumigated, but inoculum of *G. graminis* var.

*tritici* introduced. Take-all from natural inoculum (i above) was common on wheat plants in the 11th yr in plots previously planted to wheat, the grass mixture, or soybeans, but was mild or nonexistent on wheat after oats, potatoes, or alfalfa. When inoculum of *G. graminis* was introduced, take-all was severe in plots previously planted to potatoes, oats, alfalfa, or beans, whether or not the soil had been fumigated (treatments iii and iv above). In contrast, soil in plots previously planted to wheat or the grass mixture had to be fumigated before disease of such severity could develop in response to introduced inoculum of the pathogen. Soils cropped continuously to wheat or wheat in rotation with the grass mixture were suppressive to take-all; the other crops resulted in soil becoming highly conducive to take-all. Rotating with beans not only made the soil conducive to take-all, this crop apparently maintained a source of inoculum of the pathogen as well.

Additional key words: biological control.

Take-all of wheat (*Triticum aestivum* L.) caused by *Gaeumannomyces graminis* (Sacc.) Oliver & Von Arx var. *tritici* Walker can be controlled by crop rotation, apparently because the pathogen is short-lived in soil in the absence of a host (7). Take-all also is controlled with varying success by monoculture of wheat; the disease may be severe only during the initial two to four wheat crops, but may then decline in severity with successive crops of wheat (1,8,9,14,15). Take-all decline results from a natural form of biological control by agent(s) not yet identified (1,9,14). Most evidence to date indicates that the pathogen remains present after take-all declines, but no longer causes severe disease (9,14).

Of both practical and fundamental interest is the evidence that an interruption of monoculture wheat with a rotation (break) crop may upset the take-all decline phenomenon so that upon return to wheat, the cycle of severe disease followed by disease decline must occur again (9,14). Thus, oats in rotation with wheat helps eliminate the pathogen (17), but has also been reported to favor more severe take-all in a second or third wheat crop after oats compared with continuous wheat (6). Similarly with beans (3,15) and legume forage crops (10,11), although reportedly nonhosts of *G. graminis* var. *tritici* and thus beneficial in rotations to control take-all, each has been observed to favor more take-all in a second or third wheat crop compared with continuous wheat. Vojinović (16) found that take-all on wheat seedlings in sand culture was suppressed by rhizosphere soil from wheat but developed without inhibition or was favored by rhizosphere soil from sugar beet, corn, or vetch. Lemaire and Coppenet (10) also reported that soil after sugar beets or crucifers is conducive to take-all.

Convincing field evidence for the effects of rotation crops on take-all and its decline requires long-term studies that distinguish among effects of rotation crops on wheat alone, on availability of inoculum of the pathogen, and on the agent(s) responsible for take-all decline. This study was conducted to determine the effects of certain rotation crops on take-all and the decline phenomenon. A preliminary report has been published (2).

## MATERIALS AND METHODS

**Field plot design.** The research was conducted in an irrigated field at Lind, WA (annual rainfall about 25 cm) on Ritzville silt loam. The soil was pH 7.5 as measured in 0.01 M CaCl$_2$. The field had been planted to seven consecutive crops of Nugaines winter wheat (1968–1974) before being divided into rotation plots (main plots). The seven consecutive wheat crops received conventional weed control, fertilization, and sprinkler irrigation, as used commercially for irrigated wheat in the Lind area. Take-all was slow to develop in the field, but appeared as numerous distinct patches (up to 1 m across) by the fourth crop and was uniformly severe throughout the field in 1974 (seventh crop). After the wheat was harvested in late July 1974, the field was chisel-plowed and disked in September-October, and then left untouched until the following spring. The entire field was disked again and harrowed in the spring of 1975, just before the rotation crops were planted.

Six crops were planted, each in three replicates: alfalfa (*Medicago sativa* L.), potatoes (*Solanum tuberosum* L. 'Kennebec'), common beans (*Phaseolus vulgaris* L. 'Pink Kidney'), oats (*Avena sativa* L. 'Cayuse'), a grass mixture (*Agropyron intermedium* [Host.] Beauv. and *Bromus inermis* Leyss.), and cultivar Fielder spring wheat. Each main plot of a given crop was 4 × 12 m. The alfalfa, grasses, oats, and wheat each were broadcast-

sown and covered by hand raking. The potatoes were in rows 60 cm apart and were fertilized at planting time with about 300, 50, and 20 kg/ha, respectively, of N, P, and Zn. The wheat, oats, and grasses were fertilized with N only, as ammonium nitrate, at about 150 kg N/ha. The alfalfa and beans were not fertilized, although *Rhizobium* inoculum was introduced with the first planting. All plots were hand-weeded. About 10 cm of water was applied to the entire experimental area with overhead sprinklers every 7–10 days during the growing season. The alfalfa and grasses were mowed two or three times each season and the residue removed from the plots; other crops were harvested each fall. Each rotation crop was recropped in its respective main plot for 3 yr (1975–1977), except that soybeans (*Glycine max* L.) was substituted for the common beans in the second and third yr in the bean plots. In the fall of 1977, the alfalfa and grass plots were killed with the herbicide glyphosate, and the entire experimental area was tilled, fertilized with nitrogen (120 kg N/ha) and phosphorous (25 kg P/ha) and then planted to wheat, (cultivar Fielder) in the spring of 1978.

**Separation of the effects of rotation crops on wheat, the take-all fungus, and take-all decline.** A plot design was developed to help distinguish among the effects of the rotation crops on wheat only, on the take-all fungus, or on the take-all decline phenomenon (Fig. 1). One end (half) of each main plot was fumigated with methyl bromide (50 g/m$^2$) under a plastic tarp in March 1978, immediately after fertilization but about 10 days before the wheat was planted. This allowed for a comparison of the effects of rotation crops on wheat alone (fumigated soil) and wheat in the presence of natural inoculum of *G. graminis* var. *tritici* (nonfumigated soil). Eight wheat rows 40 cm apart were planted lengthwise in each main plot, with the take-all fungus introduced in

colonized oat grains into four rows on one side and autoclaved oat kernels (control) introduced into four rows on the other side. The same planter used to plant the wheat was used to introduce the inoculum or autoclaved oats, but as a separate operation, with the planter openers following the same path each time. The pathogen was introduced to help reveal whether the lack of disease after a rotation crop was due to lack of virulent inoculum or the presence of suppressive soil. The quadrants of fumigated and natural soil each with dead and live introduced inoculum of *G. graminis* var. *tritici* are hereafter referred to as subplots.

**Assessment of take-all.** The first assessment for take-all was made in April 1978, just prior to secondary root formation on the wheat plants. Twenty-five randomly selected plants from each subplot were indexed for severity of take-all on a 0–5 scale: 0 = no disease, 1 = up to half the seminal roots infected (at least one lesion each), 2 = half to all seminal roots with lesions, 3 = seminal roots infected and lesions extending into the stem base and onto the coleoptile, 4 = lesions coalesced on the coleoptile and some extending into the seedling stem, and 5 = plant dead or nearly so.

A second assessment of take-all was made in June when wheat in the fumigated subplots was headed and at full height. By that time, many plants in the nonfumigated-inoculated and fumigated-inoculated subplots were stunted, had not headed, or had headed but then died because of take-all. Disease severity was determined by counting live-headed tillers in each of five, random, 1-m lengths of the center two rows of each subplot and measuring plant height in each of six random places in the center two rows of each subplot.

Yields were determined by hand-harvesting two 5-m lengths of the two center rows of each subplot.

## RESULTS

A few wheat plants (2–4 of 25 seedlings examined) from main plots rotated with oats, alfalfa, or potatoes were indexed 1 for infection by *G. graminis* var. *tritici* (Table 1). The incidence and severity of take-all was only slightly higher on seedlings from plots rotated to grasses. However, about two thirds of the wheat seedlings from plots previously planted to wheat or beans were indexed 1 or 2 (Table 1).

When inoculum of *G. graminis* var. *tritici* was introduced into nonfumigated soil, take-all was uniformly severe (indexed 2–3) on nearly all (21–23) of the 25 wheat seedlings, regardless of the previous crop (Table 1). Introduction of inoculum into fumigated soil resulted in no greater incidence of infected seedlings, but disease severity was greater, with many plants indexed 3 or greater (Table 1).
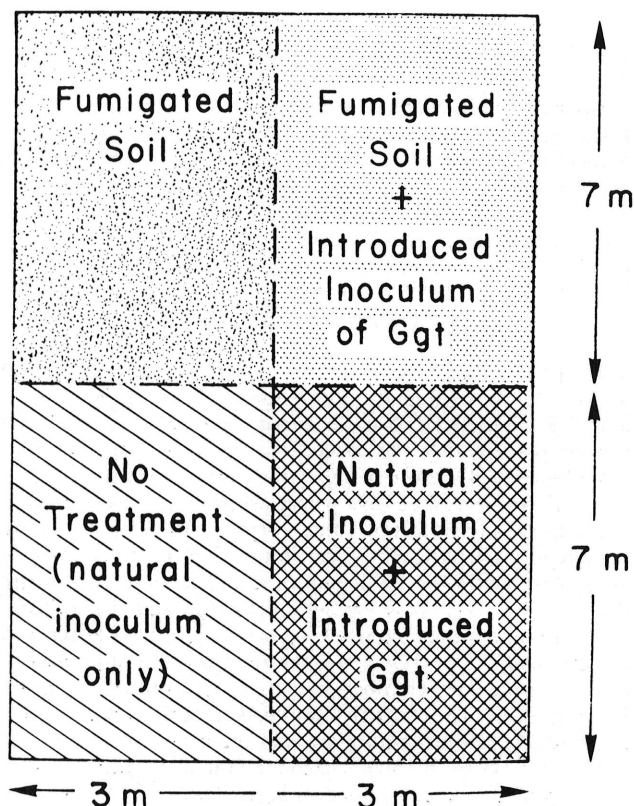
## Subplot Treatments
## Before Planting Wheat



**Fig. 1.** Design of the subplots (quadrants) used to distinguish the effects of crops prior to wheat on wheat in the absence of *Gaeumannomyces graminis* var. *tritici*, on take-all caused by natural inoculum of *G. graminis* var. *tritici*, and on suppressiveness of soil to introduced inoculum of *G. graminis* var. *tritici*.

TABLE 1. Influence of different consecutive crops grown for 3 yr prior to wheat on amount of take-all caused by natural and/or introduced inoculum of *Gaeumannomyces graminis* var. *tritici* on wheat seedlings prior to formation of secondary roots

| | Disease severity and no. of infected plants per treatment | | | | | | |
|---|---|---|---|---|---|---|---|
| | Soil not fumigated | | | | Soil fumigated | | |
| | Natural inoculum | | Natural + introduced inoculum | | Natural inoculum | | Natural + introduced inoculum |
| Previous crop | DS[a] | No.[b] | DS | No. | DS | No. | DS | No. |
| Oats | 0.2 | 4 | 2.0 | 21 | 0.1 | 1.7 | 2.8 | 21.7 |
| Potatoes | 0.1 | 3 | 2.0 | 21.7 | 0.1 | 2.3 | 2.7 | 22.7 |
| Alfalfa | 0.1 | 2 | 2.0 | 21.3 | 0 | 0 | 2.8 | 22 |
| Grasses | 0.3 | 5.7 | 2.0 | 22.7 | 0.1 | 1 | 3.2 | 23 |
| Beans[c] | 1.0 | 15 | 2.4 | 22.7 | 0 | 0 | 3.2 | 22.7 |
| Wheat | 0.9 | 13.7 | 2.4 | 23.3 | 0 | 0 | 2.6 | 23.3 |

[a] DS = disease severity rated on a scale of 0–5: 0 = no disease, 1 = up to 50% of the seminal roots with one or more lesions, 2 = 50-100% of the seminal roots with lesions, 3 = seminal roots infected and lesions extending into stem base or onto coleoptile, 4 = lesions coalesced on the coleoptile and some extending into the stem, and 5 = plant dead, or nearly so.

[b] Number of infected plants in a sample of 25; each value is the average for three replicates.

[c] *Phaseolus vulgaris* in 1975 and *Glycine max* in 1976 and 1977.

As the season progressed, take-all in plots with natural inoculum only, developed on wheat after wheat, the grass mixture, or beans, but not on wheat after potatoes, alfalfa, or oats. This was indicated by lower yields (Table 2) and to some extent more stunting at plant maturity (Fig. 2A) in wheat after wheat, after grasses, or after beans compared with wheat after the other three rotation crops. The lower yields after oats resulted from volunteer oats in the 1978 wheat crop and which were not completely eliminated by the fumigation; wheat yields after oats were consequently low, but not because of take-all.

The effects of rotation crops on the take-all decline phenomenon became evident with the second disease assessment in those subplots with introduced inoculum. For wheat following potatoes, alfalfa, oats, or beans, take-all development with introduced inoculum was equally severe whether the subplots were fumigated or not fumigated. This was indicated by only slightly taller wheat (Fig. 2A) and a few more tillers with heads per unit of row (Fig. 2B) in the nonfumigated-inoculated compared with fumigated-inoculated subplots of these rotation crops. In contrast, for wheat after wheat or the grass mixture, take-all development from introduced inoculum was suppressed, as indicated by markedly taller (Fig. 2A) and more dense (Fig. 2B) wheat in the nonfumigated-inoculated compared with fumigated-inoculated subplots of these rotations. Yields likewise were significantly higher in nonfumigated-inoculated subplots of the continuous wheat and wheat-grass treatments compared with the same treatments in the other four rotations (Table 2).

Fumigation alone resulted in increased tillering (Fig. 2) and yields (Table 2) in wheat regardless of the previous crop.

## DISCUSSION

Alfalfa, oats, or potatoes grown as rotation crops for 3 yr in plots where wheat had been grown the previous 7 yr, and where wheat was again grown in the 11th yr, gave control of take-all not significantly different from the control obtained with methyl

bromide fumigation. However, these crops also resulted in soil becoming conducive to take-all—about as conducive as the fumigated soil based on the severity of disease when inoculum was introduced. Soil in the potato plots showed some evidence of suppressiveness, but more work would be needed to verify this observation. The results were strikingly different where wheat was grown all 11 yr, or where the 3-yr break was a grass mixture; some take-all from natural inoculum was evident on essentially all wheat plants by maturity of the crop in the 11th yr of these two treatments but the soil was suppressive as indicated by only a moderate increase in take-all severity where inoculum was introduced. It was necessary to fumigate soil in the continuous wheat, or wheat-grass-wheat main plots, then add inoculum, in order to produce take-all

TABLE 2. Influence of different crops grown 3 yr consecutively prior to wheat on yield of wheat following no soil treatment (no fumigation and no additional inoculum of *Gaeumannomyces graminis* var. *tritici* introduced), soil fumigated, soil not fumigated but inoculum of *G. graminis* var. *tritici* was introduced, and soil fumigated then amended with inoculum of *G. graminis* var. *tritici*

| Previous crop | Yield per treatment[y] (kg/ha) | | | |
|---|---|---|---|---|
| | No introduced inoculum | | Introduced inoculum | |
| | No fum | Fum | No fum | Fum |
| Oats | 3,906 b | 5,060 bc | 268 d | 403 a |
| Potatoes | 6,057 a | 7,276 a | 980 c | 273 a |
| Alfalfa | 5,580 a | 6,599 ab | 278 d | 81 a |
| Grasses | 4,042 b | 5,336 bc | 1,919 b | 523 a |
| Beans[z] | 2,979 b | 4,440 c | 306 d | 81 a |
| Wheat | 3,976 b | 5,625 abc | 2,719 a | 78 a |

[y] Each value is the average for three replicates. Values within columns not followed by the same letter are significantly different at $P = 0.05$ according to Duncan's new maultiple range test.
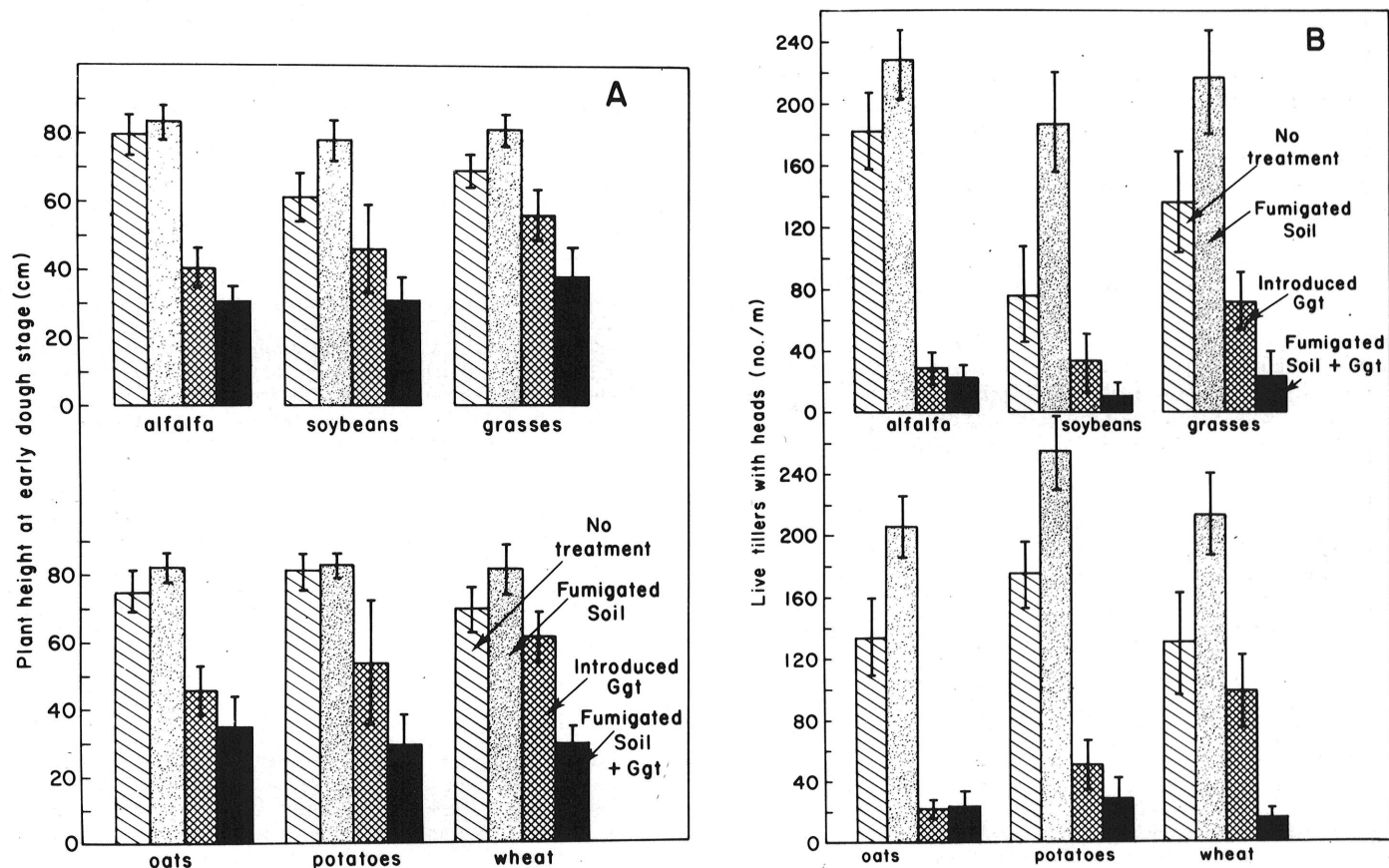[z] *Phaseolus vulgaris* in 1975, *Glycine max* in 1976 and 1977.



Fig. 2. Influence of different crops grown 3 consecutive yr prior to wheat on **A,** plant height and **B,** tiller production of wheat following fumigation or no fumigation with methyl bromide and introduction or no introduction of inoculum of *Gaeumannomyces graminis* var. *tritici*.

of the severity produced with inoculum added to nonfumigated alfalfa, oat, or potato plots. A break crop of beans produced still another effect; these crops apparently provided a source of inoculum of the pathogen as well as conducive soil.

Beans are not a generally recognized host of *G. graminis* var. *tritici*, although increased severity of take-all following soybeans is commonly recognized in the Midwest. Roy et al (13) in Indiana isolated the closely related *G. graminis* var. *graminis* from pods of soybeans and found the isolates pathogenic to roots and stems of wheat. Zogg (18) showed that *G. graminis* var. *tritici* can infect peas in sterile soil. In my study, common beans were grown only in the first yr and soybeans the second and third yr, and thus the major effect was most likely due to the soybeans.

Much of the wheat in the southeastern USA and in southern Brazil is double-cropped with soybeans; ie, wheat is grown during the winter and soybeans in the summer in the same field each year. Take-all has become an important root disease of wheat in this management system. Although other factors (eg, use of lime) can explain, in part, the severity of take-all in these areas, the soybean component of this management system also may be contributing to the take-all problem. Possibly only a small amount of inoculum is provided by the soybeans, but because the soil is so conducive to take-all after these crops, severe disease develops.

Various legume crops have been implicated as favorable to take-all because of deleterious effects on microorganisms antagonistic to the take-all fungus (3,9–11). Apparently their effect is one of counteracting take-all decline. In the northwestern USA take-all is mainly a problem in wheat after alfalfa. Grass hosts of the take-all fungus are common weeds in alfalfa stands and may provide a source of inoculum in soil made highly conducive to take-all by the alfalfa. Growers should either rotate with nonhost crops to control take-all, or use continuous wheat, but alternating between the two systems may be counterproductive. This supports the conclusion of Cox (4), that a short break in otherwise continuous wheat has little value where take-all is concerned.

Garrett (7) showed that high N facilitates survival of *G. graminis* var. *tritici* in crop refuse. High residual soil N could explain the more severe disease in wheat after alfalfa, beans, or potatoes; the soil N could have been provided by N fixation in the case of alfalfa and possibly the beans, and by the large annual applications of N in the case of potatoes. However, high residual soil N cannot explain why soil previously cropped to oats was so conducive to take-all caused by introduced *G. graminis* var. *tritici*; this crop received the same amount of N as did the wheat and grasses yet soil after oats was conducive and soil after wheat or grasses was suppressive to take-all.

Take-all in wheat after the grass mixture was slow to develop from the outset, and remained suppressed through to maturity of the crop. In England, suppression of *G. graminis* var. *tritici* on wheat following a grass ley has been attributed to antagonism from certain related fungi, especially *Phialophora graminicola* (5). Preliminary attempts to isolate *P. graminicola* from the roots of grasses and wheat from the Lind plot have thus far produced only *G. graminis* var. *tritici* (R. J. Cook, *unpublished*). Nevertheless, difference in the pattern of take-all suppression in wheat after the grasses was sufficient to suggest that different mechanisms of disease suppression may have been operative in the two cropping systems.

Tillering and, to some extent, yield of wheat were increased by fumigation of all plots regardless of the previous crop; this response was possibly from control of one or more unidentified root pathogens of wheat, or release and better distribution of plant nutrients following the fumigation (12).

Where inoculum was introduced into the suppressive soil (continuous wheat or wheat-grass-wheat plots), wheat was not protected against initial infections (as assessed in seedling stage) but rather, disease progress was checked after infection and plants tended to recover. Recovery of the wheat in these treatments was due to the development of the secondary root system which remained relatively disease-free in the suppressive soil in spite of an apparently aggressive beginning of the disease. In contrast, take-all from inoculum introduced into conducive soil (plots previously planted to oats, potatoes, alfalfa, or beans) began with no greater severity on the seedlings but advanced to the crowns and crown roots and killed most of the plants. This observation supports the suggestion (14) that in soils suppressive because of take-all decline, disease progress rather than initial infection is suppressed.

## LITERATURE CITED

1. Cook, R. J., and Rovira, A. D. 1976. The role of bacteria in the biological control of *Gaeumannomyces graminis* by suppressive soils. Soil. Biol. Biochem. 8:269–273.
2. Cook, R. J. 1979. Influence of crops besides wheat on *Gaeumannomyces graminis* and take-all decline. (Abstr.) Phytopathology 69:914.
3. Cox, J. 1963. Take-all on Broadbalk. Pages 117–118 in: Rothamsted Exp. Stn. Rep. for 1962.
4. Cox, J. 1965. Continuous wheat growing and the decline of take-all. Pages 133–134 in: Rothamsted Exp. Stn. Rep. for 1964.
5. Deacon, J. W. 1973. Control of the take-all fungus by grass leys in intensive cereal cropping. Plant Pathology 22:88–94.
6. Etheridge, J., and Slope, D. B. 1967. Continuous wheat growing and decline of take-all. Page 123 in: Rothamsted Exp. Stn. Rep. for 1966.
7. Garrett, S. D. 1956. Biology of Root-Infecting Fungi. Cambridge University Press, London and New York. 293 pp.
8. Gerlagh, M. 1968. Introduction of *Ophiobolus graminis* into new polders and its decline. Neth. J. Plant Pathol. 74. Suppl. 2. 97 pp.
9. Hornby, D. 1979. Take-all decline: A theorist's paradise. Pages 133–158 in: B. Schippers and W. Gams, eds. Soil-borne Plant Pathogens. Academic Press, London, New York, and San Francisco. 686 pp.
10. Lemaire, J. M., and Coppenet, M. 1968. Influence de la succession céréalière surles fluctuations de la gravité du Piétin-échaudage (*Ophiobolus graminis* Sacc.). Ann. Épiphytes 19:589–599.
11. Louw, H. A. 1957. The effect of various crop rotations on the incidence of take-all (*Ophiobolus graminis* Sacc.) in wheat. Science Bull. No. 379. Dept. Agric., Union of So. Africa. 12 pp.
12. Rovira, A. D. 1976. Studies on soil fumigation-I. Effects on ammonium, nitrate and phosphate in soil and on the growth, nutrition, and yield of wheat. Soil Biol. and Biochem. 8:241–247.
13. Roy, K. W., Abney, T. S., and Huber, D. M. 1976. Isolation of *Gaeumannomyces graminis* var. *graminis* from soybeans in the midwest. Proc. Am. Phytopathol. Soc. 3:284.
14. Shipton, P. J. 1975. Take-all decline during cereal monoculture. Pages 137–144 in: G. W. Bruehl, ed. Biology and Control of Soil-Borne Plant Pathogens. Am. Phytopathol. Soc., St. Paul, MN. 216 pp.
15. Slope, D. B., and Cox, J. 1964. Continuous wheat growing and decline of take-all. Page 108 in: Rothamsted Exp. Stn. Rep. for 1963.
16. Vojinović, Z. D. 1973. Antagonists from soil and rhizosphere to phytopathogens. Inst. Soil Sci., Beograd, Yugoslavia. Final Tech. Rept. 130 pp.
17. White, N. H. 1947. The etiology of take-all disease of wheat 4. The effect of agronomic practices on the incidence and severity of take-all. J. Council Sci. Ind. Res. 20:82–86.
18. Zogg, H. 1969. Crop rotation and biological soil disinfection. Qual. Plant. Mater. Veg. 18:256–273.