Competitive Saprophytic Ability of Fusarium roseum f. sp. cerealis 'Culmorum' in Soil

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ABSTRACT

Fusarium roseum f. sp. *cerealis* 'Culmorum' was not a good saprophytic colonist of wheat stems in a soil-peat-sand mixture. The soil fungi *Aspergillus niger, Chaetomium globosum*, and *Trichoderma viride* rapidly colonized untreated wheat stems placed in soil thereby preventing colonization by Culmorum. Nonsoil fungi *Alternaria tenuis* and *Helminthosporium sativum* were less successful in preventing colonization of wheat stems by Culmorum. Inability of Culmorum to colonize untreated wheat stems may partially explain the lack of increase in the population of this fungus in plots where susceptible wheat varieties have been grown for 7 years.

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Additional key words: soil fungi, saprophytic colonization.

Losses in stand and yield of wheat (*Triticum aestivum* L.) from seedling blight, root rot, and crown rot, caused by *Fusarium roseum* (Lk. ex Fr.) emend. Snyd. & Hans. f. sp. *cerealis* are usually sustained during periods of hot, dry weather (3, 5, 6, 12). For winter wheat in the Pacific Northwest, losses have been estimated to reach 50% for Fusarium root rot (7); *F. roseum* 'Culmorum' is a major component of this root-rot complex.

In Minnesota, root rot of wheat was reported more severe in 1964 than in 1963 or 1965, among 90 to 177 varieties tested (12). In 1969, root rot of 'Chris' wheat caused losses in stand and yield (19).

Culmorum has been reported by Garrett (10) to grow saprophytically in soil, probably on crop residues. It survives actively as hyphae and passively as chlamydospores. Tillage operations probably release chlamydospores from pockets of infected and decayed tissues and distribute them throughout soil.

If Culmorum has a high competitive saprophytic ability in soil, its population would not be changed appreciably by normal crop rotation (10); however, if this ability is low, crop rotation and other practices that hasten residue decomposition should reduce the inoculum potential of Culmorum and thereby effect a measure of disease control.

Thus, experiments were designed to ascertain the competitive saprophytic ability of Culmorum in a nonautoclaved soil (field soil:peat:sand mixture) in comparison with autoclaved soil artificially contaminated with certain fungi, some of which were soil inhabitants antagonistic to *Fusarium* spp., and some nonsoil fungi.

MATERIALS AND METHODS.–The soil consisted of a mixture of soil (Waukegon-Dakota loam, pH 6.8 - 7.0) from field plots at St. Paul that had a small indigenous Culmorum population and was mixed with peat and sand (6:3:1, v/v/v). This made a sandy loam (pH 6.5 - 7.0) which contained fewer than 10 colonies of Culmorum/g soil. Culmorum was isolated from soil by the soil dilution method using Nash & Snyder's (16) pentachloronitrobenzene (PCNB) medium, pH 4.5. The low number of Culmorum colonies in the soil ensured that saprophytic colonization of untreated wheat stems would be due to Culmorum inoculum added to soil. All soil was passed through a 2-mm sieve. Some soil was autoclaved at 121 C for 2 hr.

Culmorum was isolated from wheat roots and stems on PCNB medium. *Fusarium* spp. and cultivars were identified according to the scheme of Snyder & Hansen (15, 18). Fungi other than *Fusarium* spp. were isolated on acidified potato dextrose agar (APDA), pH 5.5. Nonsoil fungi were *Alternaria tenuis* Auct. and *Helminthosporium sativum* Pam., King & Bakke. Soil fungi were *Aspergillus niger* van Tieg., *Chaetomium globosum* Kze. ex Fr., *Penicillium* sp., and *Trichoderma viride* Pers. ex Fr.

Propagules of all fungi used in competition for colonization of wheat stems were increased on a 3% sand-cornmeal (w/w) medium for 14 days under natural light available in a north-facing laboratory at 24 C.

Air-dried mass inoculum of Culmorum and each test fungus, were mixed individually (w/w) in ratios of 100:0 (control), 98:2, 90:10, 50:50, 10:90, 2:98, and 0:100 (control), respectively, and distributed throughout 100 g of nonautoclaved, air-dried soil, making a total of 200 g of soil-inoculum mixture.

In another experiment the sand-cornmeal mass inoculum was adjusted to provide equal numbers of viable propagules of Culmorum and the test fungus. Propagules of each fungus were determined by successively diluting 1 g of air-dried inoculum 1:1,000 (v/v) and counting with a haemacytometer. Germination of propagules was tested on APDA after 6 to 12 hr. Numbers of viable propagules/g air-dried inoculum for each test fungus and Culmorum were then made equal by adding sterile sand to the inoculum with the most propagules. Fifty g of each inoculum were distributed throughout 100 g of

nonautoclaved soil to make a total of 200 g of soil-inoculum mixture.

In all experiments where sand-cornmeal inoculum was added to soil, the soil-inoculum mixture was incubated for an additional 14 days before the wheat stems were added to the mixture. Most of the Culmorum propagules were chlamydospores at the end of the second 14-day period.

Fifty mature wheat stem fragments (1-2 cm long) were placed in each soil-inoculum mixture and after 30 days, fungi were isolated by first washing the stems in tap water, then immersing them successively for 1-2 sec in 95% ethanol and 10 sec in 1% NaOCl, and finally placing them on either PCNB or APDA medium for a 5- to 7-day incubation period.

RESULTS.–*Colonization of stems by F. roseum 'Culmorum'.–1) Contiguous fragments.*–A modification of a technique devised by Park (17) was used to ascertain growth of Culmorum through wheat stems. Five noninoculated (autoclaved and nonautoclaved) stem fragments 5-mm long were laid end to end and touching so that the second stem fragment touched the first one which was previously colonized by Culmorum. Stems were numbered from one to six where no. 1 was colonized initially by Culmorum and succeeding numbers up to six represented stem fragments arranged in the order indicated. Stems from mature wheat plants or from 14-day-old seedlings were placed on autoclaved or nonautoclaved soil.

As shown in Fig. 1, Culmorum did not grow much from a previously colonized stem fragment (no. 1) through successive abutting stem fragments unless both soil and stems were autoclaved. However, after 7 days, Culmorum grew slower through autoclaved mature stems than through autoclaved seedling stems placed on autoclaved soil and slower through nonautoclaved mature stems than through seedling stems on nonautoclaved soil.

When stems were placed on soil for 21 days, there was little additional colonization of stems beyond that recorded for 7 days. There was, in some treatments, a reduction in incidence of Culmorum reisolated from stem no. 1 between 7 and 21 days of incubation due probably to desiccation and death of hyphae within stems.

Differences in growth of Culmorum in seedling and mature stems disappeared at 21 days except when nonautoclaved stems were placed on autoclaved soil. No stems were colonized by Culmorum in the control.

Fusarium oxysporum and *F. solani* were frequently isolated and *F. roseum* 'Equiseti', *F. roseum* 'Graminearum', *F. moniliforme*, and *F. tricinctum* infrequently isolated from stems placed on nonautoclaved soil.

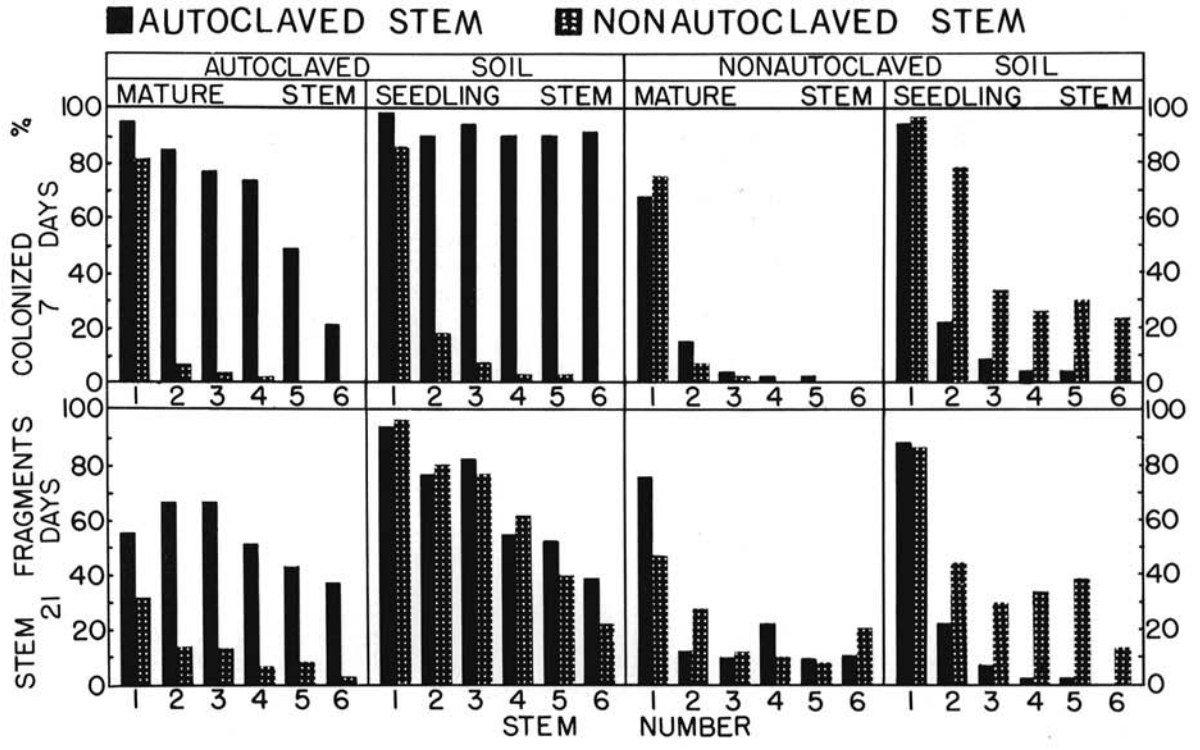

Fig. 1. The growth after 7 and 21 days of *Fusarium roseum* 'Culmorum' through successive contiguous stem fragments of either mature or seedling stems placed either in autoclaved or nonautoclaved soil. Stem no. 1 was first colonized by Culmorum and other stem fragments were laid end-to-end so each fragment touched the next one in line. Percentage colonization is based on 10 replicates of 10 stems/replicate.

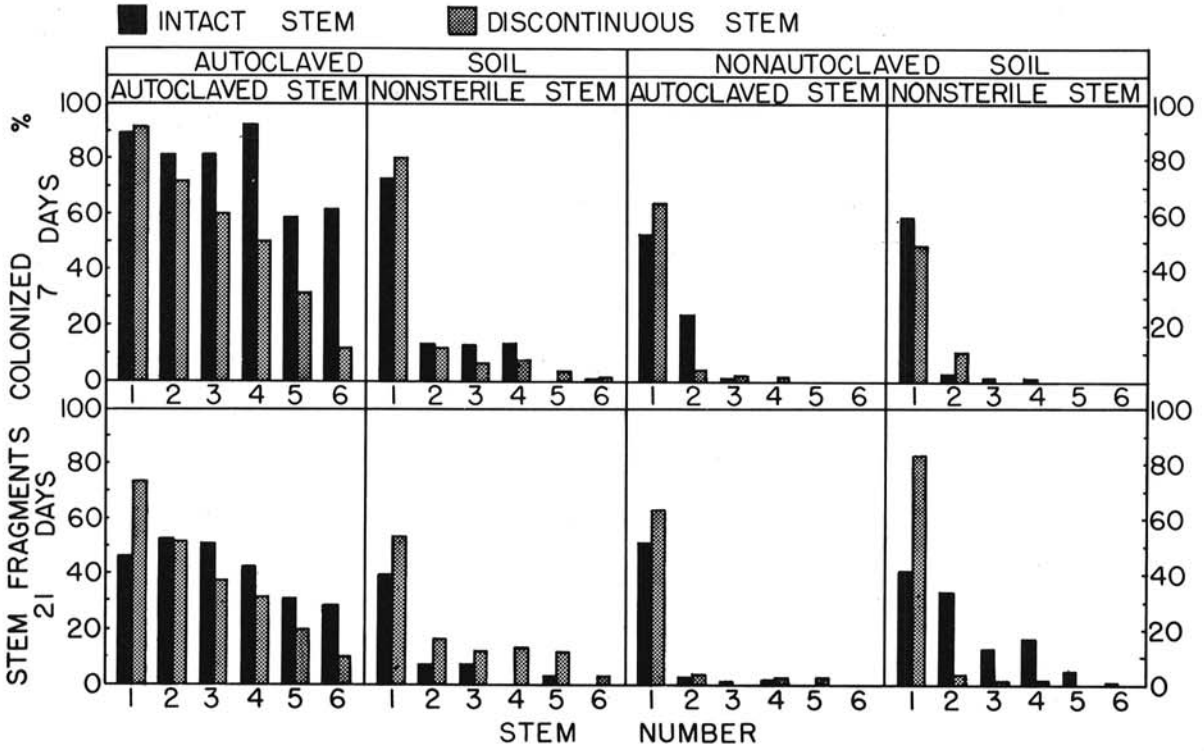

Fig. 2. Comparison in growth of *Fusarium roseum* 'Culmorum' through either intact wheat stems each 25-mm long or through disconnected stem fragments, each 5-mm long and 5-mm apart, with stems from mature plants autoclaved and nonautoclaved, placed in either autoclaved or nonautoclaved soil, and incubated for either 7 or 21 days. Stem no. 1 contained the inoculum in each trial. Data on intact stems are based on 10 replicates of 10 stems/replicate and data on discontinuous stems are based on five replicates of 10 stems/replicate.

2) Intact long stems.—Sporadic growth of Culmorum through successive stems may be due to colonization of stems by soil organisms that subsequently exclude Culmorum. Growth of Culmorum was tested along a single mature stem (25-mm long) that equaled in length five abutting stem fragments as used in the previous experiment. Culmorum growing through the length of a single long stem, unhindered by having to colonize separate stems, may grow faster through the stem than potential colonizers from soil, and thereby exclude them.

Stems (autoclaved and nonautoclaved) 25-mm long and touching a stem previously colonized by Culmorum were placed on soil (autoclaved and nonautoclaved) for 7 and 21 days. At the end of each incubation period, stems were cut into 5-mm lengths and each length was assigned a number that identified its position when the intact stem was in contact with the soil. The control was stem no. 1 which was not colonized.

Growth of Culmorum through a single stem did not proceed appreciably beyond the initially infected stem with the exception of autoclaved stems placed on autoclaved soil (Fig. 2).

3) Discontinuous fragments.—To determine if Culmorum could grow through soil and colonize stems separated by a short distance, 5-mm long mature stems (autoclaved and nonautoclaved) were placed vertically in soil (autoclaved and nonautoclaved) 5-mm apart for 7 and 21 days. Stem no. 1 was previously colonized with Culmorum. Soil was placed in a petri dish (9-cm diam) and one group of six stems was tested in each petri dish.

Colonization of stems occurred primarily when stems were placed in autoclaved soil (Fig. 2). Mycelium of Culmorum grew on top of autoclaved soil and could be seen around stems, yet only 2% and 4% of the nonautoclaved stems that were 25 mm from the food base were colonized after 7 days and 21 days, respectively. There was relatively little colonization of autoclaved stems placed in autoclaved soil; 12% of autoclaved stems were colonized at 25 mm from the food base after 7 days and 10% were colonized after 21 days.

Competitive saprophytism of Culmorum.—1) Indigenous soil microflora.—To determine if colonization of stems by soil microorganisms excluded colonization by Culmorum, mature stems (autoclaved and nonautoclaved), 5-mm long were placed on soil (autoclaved and nonautoclaved) beside a stem previously colonized for 7 days by Culmorum. At the end of each 7-day period, the most recently placed stem was thoroughly overgrown by Culmorum

which increased its potential to colonize the succeeding stem. Nonautoclaved stems were colonized least by Culmorum (Fig. 3). *Alternaria* sp. and *Helminthosporium* sp. were the predominant fungi (90% of fungus colonies) isolated from nonautoclaved stems not colonized by Culmorum. Culmorum was isolated less frequently from stem no. 1 except when autoclaved stems were placed on autoclaved soil. Culmorum was apparently reduced in stem no. 1 by either (i) desiccation of hyphae in the stem or (ii) by antagonism of other fungi or bacteria originating either from nonautoclaved stems or soil, or both (i) and (ii).

To determine how much time is necessary for mature wheat stems to be colonized by soil microorganisms which exclude Culmorum, noninfested stems were placed in nonautoclaved soil for 0, 1, 2, or 3 days. It was assumed that placing noninfested stems in nonautoclaved soil for various time periods would be indicative of the length of time it would take indigenous soil microorganisms to colonize wheat stems. Stems were then transferred to autoclaved soil and placed so that each stem touched one previously colonized by Culmorum.

Ninety-three percent of stems not exposed to soil were colonized by Culmorum. After exposure to soil for 1 day, 4% of the stems were colonized by Culmorum but no colonization by Culmorum occurred when stems were placed in soil for 2 or 3 days.

2) Competition by propagules of Culmorum and soil and nonsoil fungi in the colonization of stems.—Generally, soil fungi were more successful than fungi isolated from wheat refuse (nonsoil fungi) in competing with Culmorum for stems (Fig. 4). An exception to this was *Penicillium* sp. which did not colonize stems even when it was the only inoculum in the soil. Soil fungi colonized a small portion of stems even when their numbers in soil were low compared to the number of Culmorum propagules; at ratios of Culmorum:soil fungus of 98:2 and 90:10, Culmorum was excluded from these stems. At a ratio of Culmorum:soil fungi of 50:50, the soil fungi were dominant colonizers and occupied a higher percentage of stems than did Culmorum.

Nonsoil fungi were less successful than soil fungi in competing with Culmorum for stems. *Alternaria tenuis* and *H. sativum* were more frequently isolated from stems than was Culmorum only when there was a preponderance of inoculum of these two fungi compared to the level of Culmorum inoculum.

In another test, equal numbers of viable propagules of each fungus were used at the 50:50 ratio as a basis for testing the validity of the previous experiment. There was no difference in colonization of stems by fungi whether equal numbers of propagules or equal weights of inoculum were used. Therefore, it was assumed that adjustment of propagule counts was unnecessary and the tests were valid.

3) Colonized to noncolonized stem: Culmorum first.—The rates at which Culmorum and test fungi grew from a previously colonized food base and colonized stems were compared. Wheat stems 5-mm long, (autoclaved or nonautoclaved) were placed end to end between and touching two inoculated stems (one stem colonized by Culmorum and the other stem with a test fungus). Stems were placed on 25 g of air-dried soil (autoclaved and nonautoclaved) placed in petri dishes and initially adjusted to 40% moisture holding capacity with sterile distilled water applied with an atomizer. Petri dishes containing soil and stems were placed in polyethylene bags that were sealed to prevent soil desiccation and stored at 23 C. Bags were periodically opened to permit aeration.

Controls consisted of autoclaved and nonautoclaved stems placed end to end between and touching two stems treated as follows: (i) one stem colonized with Culmorum or one of the test fungi and the other stem not colonized, or (ii) neither stem colonized.

When either end stem was inoculated with Culmorum or one of the test fungi, Culmorum was the fungus isolated most frequently (44-80%) from the middle stem only when nonautoclaved stems were placed on autoclaved soil (Fig. 5). The test fungi were isolated most frequently from middle stems in other treatments. Two exceptions to this were *Penicillium* sp., which did not colonize the middle stem under any circumstances, and *T. viride* which colonized the middle stem under all conditions except when nonautoclaved stems were placed on nonautoclaved soil.

When a smaller (2-mm long) stem was placed between stems colonized by Culmorum or a test fungus, the test fungus colonized the middle stem first and excluded Culmorum.

4) Colonized to noncolonized stem: other soil fungi first.—Stems (5-mm long) were artificially colonized with each of the test fungi. A stem

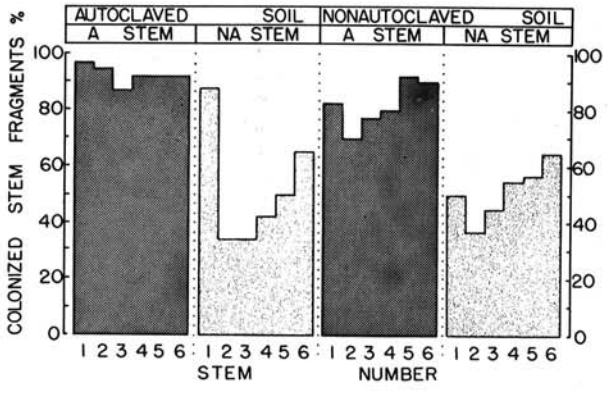

Fig. 3. The growth of *Fusarium roseum* 'Culmorum' through successive and abutting wheat stem fragments in both autoclaved (A) and nonautoclaved (NA) stems when each stem fragment was allowed to be colonized for 7 days before the next stem fragment was placed contiguous to the colonized fragment. The first precolonized fragment was labeled no. 1 and the last one no. 6. Percentage of colonized stem fragments was based on four replicates of 10 stem fragments/replicate.

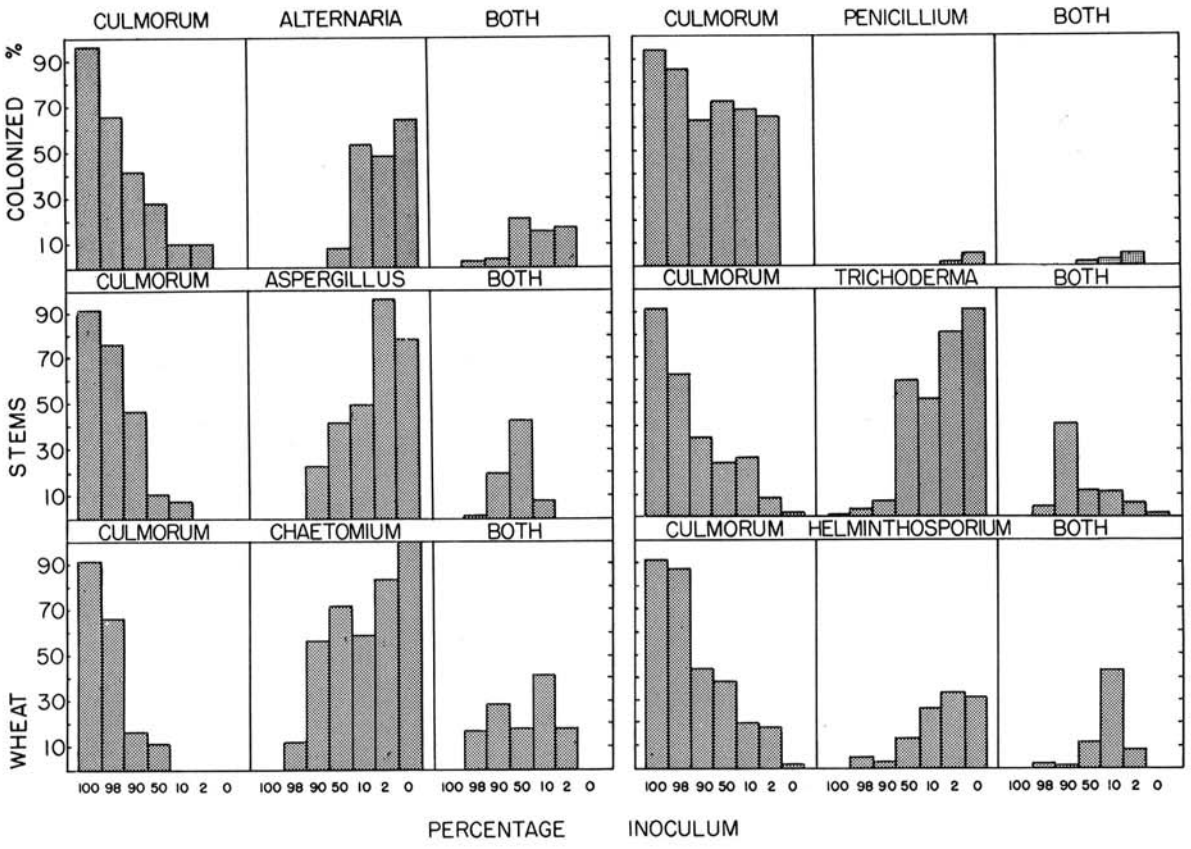

Fig. 4. Competition between *Fusarium roseum* 'Culmorum' and the test fungi for saprophytic colonization of wheat stems that were incubated in inoculum-soil mixtures for 30 days. Fungi were grown in a 3% cornmeal medium, mixed in different ratios (w/w), and placed in 100 g nonautoclaved soil. Percentage stems colonized is based on two replicates of 50 stems/replicate.

colonized by Culmorum was placed for 14 days on sterile sand and touching a stem colonized with one of the test fungi. Sterile sand was used to prevent further colonization of stems by soil fungi. Twenty-five grams of air-dried sand was added to a petri dish and moistened to 40% water-holding capacity. Moist filter paper was placed inside each petri dish cover and the petri dishes were placed in a polyethylene bag, sealed to prevent desiccation of the sand, and stored at 23 C. Autoclaved stems touching a stem colonized by Culmorum served as the control.

Culmorum did not frequently colonize stems previously colonized by other fungi (Table 1). The highest frequency of colonization by Culmorum occurred when stems were previously colonized with *H. sativum*. Culmorum alone was isolated from 4% of the stems and Culmorum and *H. sativum* were isolated from 6% of stems.

To test the possibility that production of antibiotics is a mechanism involved in the successful colonization by fungi of organic matter, a disc of APDA (5-mm diam) on which one of the test fungi had grown for 7 days, was placed next to an APDA disc on which Culmorum had grown; two discs on which the fungi had grown also were placed on opposite sides of a petri dish (9-cm diam).

There was no evidence of a zone of inhibition or antagonism between the test fungi and Culmorum. However, Culmorum was inhibited from growing over the medium by the physical occupation of the substrate by other fungi. In addition, hyphae of Culmorum were malformed and lateral branches tended to be short and stubby in appearance at the convergence of Culmorum and test fungus colonies.

DISCUSSION.—Populations of Culmorum apparently did not increase in soil on which wheat had been grown consecutively for 7 years at Rosemount, Minnesota. The population of Culmorum in soil was about 350 propagules/g each year from 1966 through 1969. Other workers have also reported that the population of Culmorum does not increase when wheat is grown successively on the same soil for several years (11). The evidence suggests that Culmorum under our experimental conditions is not a good competitor with other soil fungi in saprophytically colonizing wheat stems added to soil. The lack of saprophytic colonization by Culmorum

may account, at least partially, for the lack of population increase of Culmorum in soil. Culmorum has been categorized by Garrett (10) as a vigorous competitive sarpophyte and as such should (i) have a high linear growth rate that enables a fungus to colonize available substrate in advance of an associated organism (14); (ii) be a good utilizer of available nutrients (2), or good enzyme producer; (iii) be a producer of antibiotic toxins; and (iv) be tolerant of antibiotics produced by other microorganisms (10). A fungus that possesses these characteristics should be capable of colonizing organic matter not previously colonized as a result of parasitism.

Although Culmorum in some experiments colonized wheat stems placed in nonautoclaved soil,

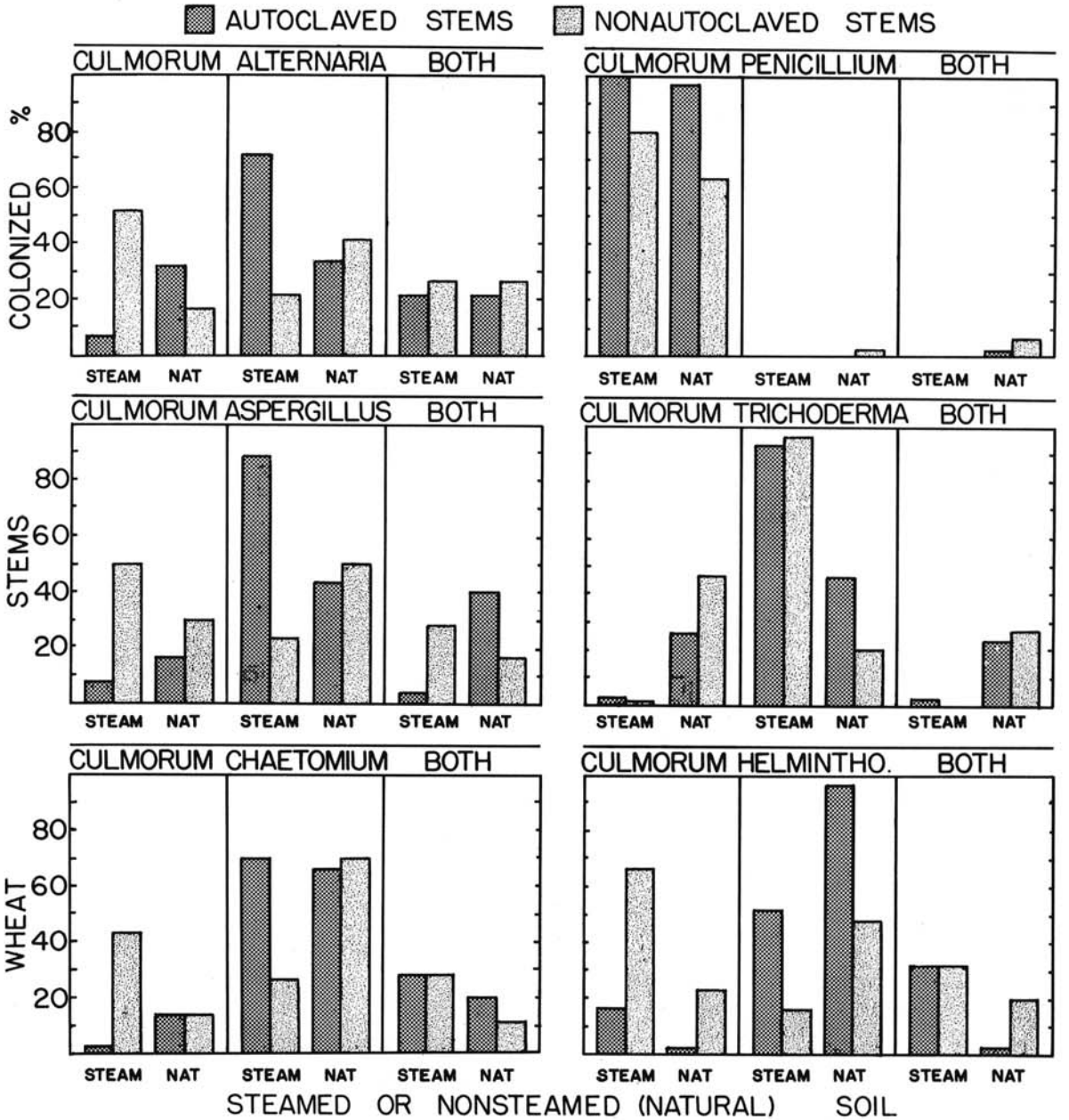

Fig. 5. Competition between *Fusarium roseum* 'Culmorum' and test fungi for saprophytic colonization of wheat stems by growth from stems previously colonized by either Culmorum or one of the test fungi. Autoclaved and nonautoclaved stems (5-mm long) were placed between and touching two wheat stems infected with either Culmorum or the test fungus and placed on either autoclaved or nonautoclaved soil. Stem fragments examined represented the middle fragment. Percentage colonization of stems is based on five replicates, 10 stems/replicate. "Steam" = autoclaved soil and "Nat" (natural) = nonautoclaved soil.

TABLE 1. Incidence of wheat stems colonized by *Fusarium roseum* 'Culmorum' following a prior infestation by species of *Alternaria, Aspergillus, Chaetomium, Helminthosporium, Penicillium* and *Trichoderma*

Original colonizing fungus in straw	Incidence of fungi isolated from stem[a]				
	Culmorum only (%)	Culmorum + *Alternaria* (%)	*Alternaria* only (%)	Culmorum + *Aspergillus* (%)	*Aspergillus* only (%)
Culmorum	94	5	1		
Alternaria	2	3	95		
Culmorum	100			0	0
Aspergillus	0			0	100
		Culmorum + *Chaetomium*	*Chaetomium* only	Culmorum + *Helminthosporium*	*Helminthosporium* only
Culmorum	4	36	60		
Chaetomium	0	1	99		
Culmorum	70			25	5
Helminthosporium	4			6	90
		Culmorum + *Penicillium*	*Penicillium* only	Culmorum + *Trichoderma*	*Trichoderma* only
Culmorum	79	8	13		
Penicillium	3	6	91		
Culmorum	41			21	38
Trichoderma	1			0	99

[a] Two wheat stems, one infested with Culmorum and the other infested with either *Alternaria, Aspergillus, Chaetomium, Helminthosporium, Penicillium*, and *Trichoderma*, were placed end-to-end and touching on washed sand for 14 days. Percentage colonization was based on 10 replicates, 10 wheat stems per fungus/replicate.

even under conditions of high soil to Culmorum-inoculum ratios, the inoculum was well distributed throughout the soil and every stem presumably was in contact with several Culmorum propagules and subsequently became colonized. Conversely, whereas Culmorum colonized fresh organic matter that was in direct contact with propagules, organic matter was not colonized if separated by a distance, however slight, from a Culmorum propagule or a food base previously colonized by Culmorum.

Culmorum competed unsuccessfully against indigenous soil fungi such as *A. niger, C. globosum*, and *T. viride* for saprophytic colonization of dead organic matter. When soil fungi and Culmorum propagules were present together in soil, Culmorum rarely colonized organic matter which was first colonized and physically occupied by faster-growing soil fungi. Prior colonization of substrate by soil fungi to the exclusion of other saprophytic fungi has been demonstrated by Leach in 1939 with *Armillaria mellea* (13). Branches of tea plants were left on the soil surface for a period of time and became colonized by soil fungi which subsequently prevented colonization by *A. mellea*. Barton also concluded that pre-colonization of organic matter by saprophytes significantly reduced colonization by *Pythium mamillatum* (1). Cook demonstrated that colonization of clean, bright unweathered straw by Culmorum was several-fold greater than that of weathered straw buried in the same soil and under the same conditions (8).

Culmorum competed somewhat more successfully for colonization of organic matter against fungi such as *A. tenuis* and *H. sativum* which ordinarily are not considered as soil fungi but which are often isolated from straw fragments.

In general, Culmorum colonized wheat stems added to soil only when one stem was thoroughly occupied by Culmorum before it could become colonized by other soil microorganisms.

Some stems not colonized by soil fungi apparently were colonized by fungi such as *H. sativum* and *A. tenuis* while the stems were still standing upright in the field, which precludes subsequent colonization of them by Culmorum. Soil fungi apparently are better adapted than Culmorum for growth in organic matter placed on soil whereas Culmorum competes successfully with nonsoil fungi for colonization of organic matter placed in soil.

Saprophytic growth by Culmorum apparently does not proceed significantly beyond the tissues of stems colonized during parasitism (9) and is precluded by the occupation of substrate by other fungi (4, 8).

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