Survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* in Maize Stalk Residue

T. K. Cotten and G. P. Munkvold

Department of Plant Pathology, Iowa State University, Ames 50011.
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ABSTRACT

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The roles of residue size and burial depth were assessed in the survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* in maize stalk residue. Stalk pieces (small or large sizes) were soaked in a spore suspension of *F. moniliforme*, *F. proliferatum*, or *F. subglutinans* and placed in a field on the soil surface or buried at 15- or 30-cm depths. Residue pieces were recovered periodically, cultured on a selective medium, and microscopically examined for the presence of the inoculated *Fusarium* species. After 630 days, the inoculated *Fusarium* species were recovered from 0 to 50% of the inoculated stalk pieces in a long-term, continuous maize field, from 0 to 28% of the inoculated stalk pieces placed in a maize/soybean/oat rotation field, and from 0 to 25% of the noninoculated stalk pieces at both locations. Residue size and residue

depth had significant effects on survival, but there were significant interactions among strain, depth, residue size, and time. Up to 343 days after placement in the field, survival of the three *Fusarium* species was not consistently different between buried residues and surface residues, but after 630 days, survival was greater from surface residues. Overall, fungus survival decreased more slowly in the surface residues than in the buried residues. Linear coefficients of determination ranged from 0.35 to 0.82 for the surface residues and from 0.81 to 0.98 for the buried residues. Decline in survival over time followed a more linear pattern in buried residues than in surface residues. Vegetative compatibility tests confirmed that *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* strains can survive at least 630 days in surface or buried maize residue. These results demonstrate that maize residue can act as a long-term source of inoculum for infection of maize plants by these three *Fusarium* species.

Additional keywords: corn, *Gibberella fujikuroi*.

Fusarium moniliforme J. Sheld. (= *Fusarium verticillioides* (Sacc.) Nirenberg), *F. proliferatum* (T. Matsushima) Nirenberg, and *F. subglutinans* (Wollenweber & Reinking) P.E. Nelson, T.A. Toussoun, & Marasas are the most commonly reported fungal species associated with maize plants (*Zea mays* L.) in the United States (4,14,20,29). One or more of these species can be found in plants or residue in virtually every maize field in the United States at some time during the growing season (14,15,20,30,32). As currently described, *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* have a common teleomorph, *Gibberella fujikuroi* (Sawada) Ito in Ito & K. Kimura. *G. fujikuroi* consists of at least seven genetically distinct biological species or mating populations (19). These mating populations are generally not interfertile, and each mating population corresponds to one or more anamorph species (16,17). The anamorph species *F. moniliforme* corresponds to mating population A, *F. proliferatum* corresponds to mating population C or D, and *F. subglutinans* corresponds to mating population B or E. All three species are included in *Fusarium* section *Liseola* based on morphological characteristics (32). These *Fusarium* species can cause seedling disease, root and crown rot, stalk rot, and ear rot on maize.

In addition to causing plant disease, these fungi can produce mycotoxins including fumonisins, a recently described class of mycotoxins that are mainly produced by *F. moniliforme* and *F. proliferatum* (11,21,28,31). Fumonisins are the most common toxins found in diseased and symptomless maize kernels in the midwestern United States (1,2,21,31). Fumonisin B1 can cause leukoencephalomalacia in horses and pulmonary edema in swine, as well as liver damage and cancer in laboratory animals (31,36). Fu-

monisins also are suspected to cause human esophageal cancer (31). *F. subglutinans* does not produce fumonisins, but it produces other important mycotoxins (21,28). In addition to fumonisins, other toxic metabolites produced by these fungi include fusaric acid, fusarins, and moniliformin (28). The implications of fumonisin toxicity in grain and food are serious. Therefore, an understanding of inoculum sources for *Fusarium* infection of kernels is important.

Traditionally, maize residues have been considered a major inoculum source of fungi pathogenic to maize. Surface residues are the main inoculum source for *Colletotrichum graminicola* (anthracnose leaf blight and stalk rot), *Cercospora zeae-maydis* (gray leaf spot), *Exserohilum turcicum* (Northern corn leaf blight), *Kabatella zeae* (eyespot), and *Bipolaris maydis* (Southern corn leaf blight) (3,7,22-24,39). All of these diseases have been shown to increase in severity in reduced-tillage or no-tillage situations (3,5,7,12,22-24,39).

Maize residues may also be a major inoculum source for *Fusarium* species. However, few experiments have studied the survival of *F. moniliforme*, *F. subglutinans*, and *F. proliferatum* in maize residue under field conditions. Liddell and Burgess (22) demonstrated that *F. moniliforme* microconidia can survive up to 900 days under various humidity and temperature conditions in the laboratory. *F. moniliforme* conidia and hyphae survived two Kansas winters in sorghum stalks without any loss of viability or pathogenicity (27). Nyvall and Kommedahl (33) studied the survival of *F. moniliforme* for 8 months in maize stalk residue in an Iowa field. They observed a longer survival duration for residue buried at 30 cm than for surface residue. It is unknown whether the recovered fungus was actually *F. moniliforme*. At the time of publication of the paper (1970), *F. subglutinans* and *F. proliferatum* had not been separated from *F. moniliforme* (32).

The relationship between the presence of residue in the field and disease severity is unclear. Severity of root and stalk rot caused by *F. moniliforme* is often lower in fields with surface

Corresponding author: G. P. Munkvold; E-mail address: munkvold@iastate.edu

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residue than in plowed fields (4,10,26,35). Skoglund and Brown (37) found higher rhizosphere population densities of *F. moniliforme* and *F. subglutinans* in no-till and chisel-tilled fields compared with plowed fields, but the percentage of plants infected with stalk rot in each tillage treatment was not significantly different. Leslie et al. (20) found that *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* were common in host tissue, but were not common in crop residues or soil.

Because published data on long-term field survival of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* in maize are limited to the single, 8-month experiment reported by Nyvall and Kommedahl (33), further studies are needed to assess the role of residue as an inoculum source for *Fusarium* diseases, especially kernel infection, under different tillage and cropping systems. In a maize/soybean rotation system, survival of *Fusarium* species for more than 1 year would enhance the importance of residue as an inoculum source for kernel infection.

The objective of this research was to determine the duration that specific strains of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* can survive in maize stalk residue under field conditions. We also assessed the effects of residue size and residue depth on the survival of these fungi.

MATERIALS AND METHODS

We isolated strains of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* (designated as FM05, FP37, and FS100, respectively) from maize grown in Iowa by culturing whole kernels on Nash-Snyder medium (NSM) (32). Single spores of each strain were transferred to carnation leaf agar (CLA) and identified according to the descriptions from Nelson et al. (32). Mating population designation of the strains was determined by mating them with strains of known mating population obtained from the Pennsylvania State University *Fusarium* Research Center. Sexual crosses were performed on carrot juice agar as described by Klittich and Leslie (13). FM05 belonged to mating population A, FP37 belonged to mating population D, and FS100 belonged to mating population E.

In mid-August 1994, stalks of 3,000 maize plants (hybrid 3563; Pioneer Hi-Bred International, Inc., Des Moines, IA) were cut at the base, air-dried, and cut into pieces of two different lengths. The larger size was 13- to 15-cm long and consisted of one node and one complete internode. The smaller size was 6- to 8-cm long and consisted of one-half of an internode. Large stalk pieces were placed in 30 × 20-cm fiberglass mesh bags, and small stalk pieces were placed in 30 × 15-cm mesh bags. Stalk residue was not sterilized prior to the experiment.

We initiated field experiments in November 1994 to assess the survival of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* in maize residue. Identical plots were established at the Iowa State University Curtiss Farm, Ames, in a maize/soybean/oat rotation field and at the Iowa State University Beef Nutrition Farm, Ames, in a long-term, continuous maize field. Maize had been grown in both fields in 1994.

A spore suspension (10^4 spores per ml) of each strain was prepared from 7-day-old CLA cultures and sterile distilled water. Bagged stalk residue was inoculated with separate strains of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* by soaking in a spore suspension for 18 to 20 h; after draining, the stalks were incubated for 4 to 5 days in plastic bags at 15 to 18°C to allow colonization of stalk tissue by the fungi. Stalk pieces were then allowed to air-dry on a greenhouse bench for 48 h (stalks inoculated with different strains were in different rooms). Control treatments were noninoculated, nonsoaked stalk pieces in mesh bags. Ten stalk pieces from each inoculated treatment were surface-disinfested and cultured on NSM to assess initial incidence of colonization by the inoculated species.

For ease of sampling, a nested experimental design with four replicated blocks was used. Treatments were nested in the fol-

lowing hierarchy: three *Fusarium* strains (plus the noninoculated control), seven sampling dates, three depths of residue placement, and two residue sizes. Each main plot (*Fusarium* strain or control) consisted of seven subplots (sampling date); each subplot consisted of a hole excavated with a tractor-mounted post-hole auger (30.5-cm diameter). Within each hole, mesh bags containing stalk residues were placed at 30- and 15-cm depths (one of each size bag at each depth). Holes were filled such that the soil profile remained as intact as possible. One bag of each size was then anchored on the soil surface (0 cm) with wire loops. At Curtiss Farm, each bag contained 10 stalk pieces. At Beef Farm, the large bags contained 10 stalk pieces, and the small bags contained 7 stalk pieces. Experiments were initiated on 2 November 1994 at Curtiss Farm and 9 November 1994 at Beef Farm. Plots remained fallow during the duration of the experiment, and weeds were controlled by hand.

Samples were taken at 28- to 91-day intervals (when the soil was not frozen) over a 630-day period. At each sampling date, all six bags from one randomly selected subplot in each main plot were collected and stored at 4°C until processed. The number of stalk pieces examined for each sampling date was 960 for Curtiss Farm and 816 for Beef Farm. Stalks pieces were rinsed for 5 min with running tap water and dried for 1 week at 21 to 27°C in a growth chamber or on a greenhouse bench in wire baskets. The center section (2-cm long) of each stalk piece was excised, cut into quarters, surface-sterilized for 2 min in 0.5% sodium hypochlorite, and cultured on NSM amended with rose bengal (10 mg/liter) to slow fungal growth. After incubation at room temperature for 4 to 5 days, each stalk piece was examined for the presence of colonies of *F. moniliforme*, *F. proliferatum*, or *F. subglutinans*. Identification of fungal colonies was based upon colony morphology and microscopic examination of microconidia and conidiophores, using the criteria of Nelson et al. (32). Data were recorded as the percentage of stalk pieces from which *F. moniliforme*, *F. proliferatum*, or *F. subglutinans* were recovered. Data recorded for each treatment included only the *Fusarium* species inoculated for that treatment, but may have included the inoculated strain as well as other strains of the same species. For the control treatment, presence of any of the three species (*F. moniliforme*, *F. proliferatum*, and *F. subglutinans*) was recorded. Other *Fusarium* species, although recovered, were not recorded.

Inoculated strains were differentiated from other *Fusarium* strains by vegetative compatibility tests (18) conducted using nitrate-nonutilizing (*nit*) mutants as described by Correll et al. (6) and Klittich and Leslie (13). Three arbitrarily chosen *Fusarium* isolates from each bag were tested for vegetative compatibility with the inoculated strains. Recovered isolates that were vegetatively compatible with the inoculated strains were assumed to be the inoculated strains. On the last sampling date, a few bags yielded less than three *Fusarium* isolates; therefore, zero to two isolates were tested for these bags.

Data analysis. The percentage of stalk pieces from which *G. fujikuroi* was isolated was analyzed with repeated measures analysis of variance (PROC GLM, Statistical Analysis Systems, Cary, NC) to detect any effects of strain, residue size, depth, or interactions of these factors on *Fusarium* survival over time. Analysis of variance was also performed on individual sampling dates to determine differences in survival between the inoculated residue treatments and the control treatments. Linear regression analysis of the survival trends was performed with the Regression Tool in Microsoft Excel (version 5.0; Microsoft Corp., Redmond, WA).

RESULTS

F. moniliforme, *F. proliferatum*, and *F. subglutinans* were recovered from maize residue after 630 days in both experiments (Figs. 1 and 2). The main effects of depth and residue size on survival were significant at both locations. After 630 days, survival

of all three species was greatest in the surface residues at both locations. The interactions between depth and residue size ($P = 0.0230$) and between strain and residue size ($P = 0.0320$) were significant at Curtiss Farm, indicating the effects of depth and size were not consistent among strains (Table 1).

Effects of strain and residue depth interacted significantly with time at both locations ($P < 0.01$). The three-way interaction between time, strain, and depth was significant only at Curtiss Farm ($P = 0.0084$), indicating that the effects of depth and strain were not consistent among the treatment combinations (Tables 1 and 2).

Linear regression slopes for fungus survival over time in surface residues were consistently less negative than those for the buried residues at both locations (Tables 3 and 4). Coefficients of determination for the surface residues were also lower than coefficients for buried residues. Coefficients for buried residues ranged from 0.81 to 0.98 at Curtiss Farm and from 0.82 to 0.98 at Beef

Farm. Coefficients for surface-residue treatments ranged from 0.35 to 0.76 at Curtiss Farm and from 0.35 to 0.82 at Beef Farm.

The three *Fusarium* species were recovered from a consistent percentage of the noninoculated controls at both locations (Fig. 3). Recovery of the appropriate *Fusarium* species was significantly greater in each of the inoculated treatments than in the controls throughout the experiment, except for the last date at both locations. Recovery of all three *Fusarium* species was significantly greater ($P = 0.009$) from the noninoculated surface residues than from the noninoculated buried residues (Fig. 3).

Inoculated strains of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* still were present in the residue after 630 days in the field (Fig. 4). However, some recovered *Fusarium* isolates were not vegetatively compatible with the inoculated strains or did not form *nit* mutants after several attempts, so it was not possible to determine their vegetative compatibility. Recovery of the inocu-

Fig. 1. Percentage of inoculated maize residue pieces from which *Fusarium moniliforme*, *F. proliferatum*, or *F. subglutinans* were recovered at Curtiss Farm. M = *F. moniliforme*-inoculated, P = *F. proliferatum*-inoculated, and S = *F. subglutinans*-inoculated. Data are percentage of stalk pieces from which the inoculated *Fusarium* species was recovered (mean of four replicate blocks).

Fig. 2. Percentage of inoculated maize residue pieces from which *Fusarium moniliforme*, *F. proliferatum*, or *F. subglutinans* were recovered at Beef Farm. M = *F. moniliforme*-inoculated, P = *F. proliferatum*-inoculated, and S = *F. subglutinans*-inoculated. Data are percentage of stalk pieces from which the inoculated *Fusarium* species was recovered (mean of four replicate blocks).

lated strains from inoculated treatments was significantly greater than from the controls at all sampling dates ($P < 0.0001$). In the control treatments, isolates vegetatively compatible with one of the inoculated strains were recovered from two stalk pieces at each location over the course of the experiment. No more than one such isolate was recovered during a single sampling date. This was equivalent to 0.13% of the stalk pieces examined in the control treatments (four pieces of 3,108 total).

TABLE 1. Analysis of variance results for survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* strains over a 630-day period from inoculated maize residue^a placed in the field at 0-, 15-, or 30-cm deep at Curtiss Farm near Ames, IA^b

Source	df	F value	P > F
Strain	2	2.72	0.0781
Depth	2	4.33	0.0199
Strain × depth	4	2.45	0.0615
Size	1	7.99	0.0073
Strain × size	2	3.76	0.0320
Depth × size	2	4.15	0.0230
Block	3	2.85	0.0492
Strain × block	6	3.73	0.0048
Depth × block	6	0.70	0.6518
Size × block	3	0.47	0.7054
Time	6	98.98	0.0001
Time × strain	12	2.78	0.0014
Time × depth	12	7.57	0.0001
Time × strain × depth	24	1.90	0.0084
Time × size	6	1.24	0.2881
Time × strain × size	12	0.50	0.9151
Time × depth × size	12	1.79	0.0510
Time × block	18	1.38	0.1431
Time × strain × block	36	1.74	0.0081
Time × depth × block	36	1.02	0.4408
Time × size × block	18	0.64	0.8669

^a Maize stalk residues were 6- to 8-cm or 13- to 15-cm long.

^b Sampling units were bags of 10 residue fragments.

TABLE 2. Analysis of variance results for survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* strains over a 630-day period from inoculated maize residue^a placed in the field at 0-, 15-, or 30-cm deep at Beef Farm near Ames, IA^b

Source	df	F value	P > F
Strain	2	3.18	0.0522
Depth	2	7.85	0.0013
Strain × depth	4	0.24	0.9137
Size	1	14.87	0.0004
Strain × size	2	2.02	0.1465
Depth × size	2	0.62	0.5427
Block	3	4.91	0.0054
Strain × block	6	1.47	0.2127
Depth × block	6	0.94	0.4753
Size × block	3	2.55	0.0691
Time	6	73.12	0.0001
Time × strain	12	2.63	0.0059
Time × depth	12	4.19	0.0001
Time × strain × depth	24	1.06	0.3956
Time × size	6	0.30	0.9326
Time × strain × size	12	1.18	0.3140
Time × depth × size	12	1.30	0.2409
Time × block	18	1.20	0.2764
Time × strain × block	36	1.15	0.2722
Time × depth × block	36	0.84	0.7317
Time × size × block	18	0.96	0.5129

^a Maize stalk residues were 6- to 8-cm or 13- to 15-cm long.

^b Sampling units were bags of 10 large residue fragments or 7 small residue fragments.

Differences in stalk composition and integrity between treatments were evident by the end of the experiment. Buried residue had decomposed to rind fragments, and stalk pieces were often indistinguishable from each other. However, surface residues still were intact and had degraded little from the initiation of the experiment. Decomposition differences between buried and surface residues also were evident in the noninoculated controls. Moisture content of surface residues fluctuated more than of buried residue. When collected, buried residues were consistently moist, but surface residues usually were dry.

DISCUSSION

Our recovery of *Fusarium* species in maize residue after 630 days in a fallow field indicates that residue can be a long-term

TABLE 3. Linear regression analysis results for survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* strains over a 630-day period from inoculated maize residue^a placed in the field at 0-, 15-, or 30-cm deep at Curtiss Farm near Ames, IA^b

Strain	Depth (cm)	Residue size	Slope	y-Intercept	R ²
<i>F. moniliforme</i>	0	Small	-0.0010	0.7030	0.55
	0	Large	-0.0009	0.7154	0.35
	15	Small	-0.0013	0.8340	0.81
	15	Large	-0.0014	0.8628	0.90
	30	Small	-0.0013	0.8869	0.92
	30	Large	-0.0014	0.8907	0.89
<i>F. proliferatum</i>	0	Small	-0.0012	0.8687	0.76
	0	Large	-0.0012	0.8758	0.59
	15	Small	-0.0013	0.8372	0.84
	15	Large	-0.0015	0.8846	0.92
	30	Small	-0.0016	0.9842	0.90
	30	Large	-0.0014	0.9151	0.94
<i>F. subglutinans</i>	0	Small	-0.0011	0.7046	0.54
	0	Large	-0.0011	0.8363	0.70
	15	Small	-0.0014	0.8839	0.88
	15	Large	-0.0014	0.9111	0.84
	30	Small	-0.0014	0.9391	0.94
	30	Large	-0.0015	0.9792	0.98

^a Maize stalk residues were 6- to 8-cm or 13- to 15-cm long.

^b Sampling units were bags of 10 residue fragments.

TABLE 4. Linear regression analysis results for survival of *Fusarium moniliforme*, *F. proliferatum*, and *F. subglutinans* strains over a 630-day period from inoculated maize residue^a placed in the field at 0-, 15-, or 30-cm deep at Beef Farm near Ames, IA^b

Strain	Depth (cm)	Residue size	Slope	y-Intercept	R ²
<i>F. moniliforme</i>	0	Small	-0.0008	0.8022	0.46
	0	Large	-0.0014	0.8955	0.82
	15	Small	-0.0016	0.9253	0.90
	15	Large	-0.0014	0.8709	0.89
	30	Small	-0.0015	1.0107	0.86
	30	Large	-0.0017	0.9458	0.94
<i>F. proliferatum</i>	0	Small	-0.0012	0.9323	0.71
	0	Large	-0.0013	0.8673	0.81
	15	Small	-0.0014	0.9755	0.89
	15	Large	-0.0015	0.8692	0.89
	30	Small	-0.0014	0.9072	0.93
	30	Large	-0.0016	0.9564	0.98
<i>F. subglutinans</i>	0	Small	-0.0009	0.7763	0.35
	0	Large	-0.0011	0.7692	0.69
	15	Small	-0.0015	0.8368	0.88
	15	Large	-0.0013	0.7753	0.82
	30	Small	-0.0015	0.8441	0.89
	30	Large	-0.0015	0.8777	0.93

^a Maize stalk residues were 6- to 8-cm or 13- to 15-cm long.

^b Sampling units were bags of 10 large residue fragments or 7 small residue fragments.

source of *Fusarium* inoculum for infection of maize plants. Survival of inoculated strains was demonstrated by (i) significantly greater recovery of the appropriate *Fusarium* species from inoculated residue than from noninoculated residue, and (ii) significantly greater recovery of strains vegetatively compatible with the inoculated strains from inoculated residue than from noninoculated residue. For the final sampling date (630 days), recovery of inoculated species was not significantly different between inoculated and control treatments, but the vegetative compatibility results confirmed that the inoculated strains were still present. These two pieces of evidence together suggest that the limit of survival for these fungi was near 630 days. The value of the vegetative compatibility testing was to add support to the analysis of variance results for the species recovery data.

Some of the *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* strains recovered at the end of the experiment were not the inoculated strains. These strains were either present in the stalks prior to inoculation or they were present in the field and colonized the residue after it was placed in the field. Nevertheless, these strains would be as likely to serve as inoculum for maize plants as would the inoculated strains.

In samples collected after 343 days or less, survival of *Fusarium* species in the buried residues was equal to, if not greater than, survival of *Fusarium* species in the surface residues. This result was similar to the findings of Nyvall and Kommedahl (33), who found that the best survival of *F. moniliforme* after 8 months was in residue buried at 30 cm. However, we found that survival of *Fusarium* species was greater in surface residues than in buried residues in samples collected after 529 and 630 days. The higher recovery from the surface residues may be a result of survival of

inoculated strains or colonization in the field; surface residues were continuously exposed to external inoculum.

The survival of *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* in buried residue decreased linearly. However, a linear model less adequately described survival in surface residues. The non-linearity was probably due to two factors: environmental fluctuations in temperature and moisture, and recolonization of residues by other strains of the inoculated species. Surface residues were exposed to a wider range of temperature and moisture extremes than the buried residues. In addition, surface residues typically were dry when collected, while buried residues were always wet; decomposition of surface residues probably was limited by lack of moisture.

The possibility of recolonization of surface residue by airborne inoculum may be important in the disease cycles of *Fusarium* species. Even if specific *Fusarium* strains do not survive more than 2 years, the surface residue itself may last much longer, acting as a reservoir for *Fusarium* strains that annually recolonize residue and subsequently produce spores for dissemination. Until the residues degrade, the potential for spore production and maize plant infection still exists. Therefore, the significance of long-term survival of *Fusarium* strains in maize residue may be tempered by periodic colonization of the residues by airborne spores; long-term survival of residue may be as important for inoculum production as the long-term survival of the fungi themselves.

These conclusions are supported by previous research. Ooka and Kommedahl (34) suggested that *F. moniliforme* may multiply rapidly during the growing season on residues and leaf surfaces or in rainwater trapped in leaf sheaths. Wind, rain, or insects could disseminate propagules from any of these surfaces to the ears, silks, or leaf sheaths (9,34,38,40), or to residue in other fields.

Fig. 3. Percentage of noninoculated maize residue pieces from which *Fusarium moniliforme*, *F. proliferatum*, or *F. subglutinans* were recovered. **A**, Curtiss Farm and **B**, Beef Farm. Data are percentage of stalk pieces from which any of the three *Fusarium* species were recovered (mean of four replicate blocks).

Fig. 4. Percentage of recovered *Fusarium* isolates that were vegetatively compatible with inoculated strains. **A**, Curtiss Farm and **B**, Beef Farm. Data are percentage of vegetatively compatible isolates recovered from three arbitrarily chosen residue pieces from each inoculation treatment (mean of four replicated blocks). Data are combined for all residue sizes and burial depths.

Fusarium species were consistently detected in the control treatments. Some of these fungi may have been present in the stalks when first collected, or they originated from residue already in the field or from airborne inoculum in the case of the surface residue. No additional plant residue was introduced during the experiments, because both fields remained fallow. The presence in the controls of endemic *Fusarium* strains that were vegetatively compatible with the inoculated strains was insignificant (mean of 0.13% of all stalk residues).

Prevention of mycotoxin contamination in grain depends on the prevention of kernel infection. Greater recovery from surface residues than from buried residues at the end of our experiments suggests that tillage could reduce inoculum sources for these fungi. However, we did not test this hypothesis directly; furthermore, tillage also can influence diseases by other mechanisms. For example, the incidence of stalk rot has been shown to be lower in no-till or reduced-tillage fields compared with plowed fields (4, 10, 25), apparently due to the decrease of late-season moisture stress when residue is left on the surface. Reduced-tillage fields maintain higher and more consistent soil moisture throughout the growing season than do tilled fields (8, 39), resulting in less plant stress and a reduction in stalk rot. Furthermore, tillage of individual fields may not significantly reduce airborne *Fusarium* inoculum where neighboring fields have abundant surface residue. Further research is needed to determine whether tillage significantly reduces levels of airborne inoculum.

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