Wind and Rain Dispersal of Fusarium moniliforme in Corn Fields

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ABSTRACT

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During the 1972 and 1973 growing seasons, an Andersen air sampler was used to monitor populations of *Fusarium moniliforme* in a corn field. Colonies of *F. moniliforme* ranged from 8 to 78×10^4/liter air in 1972 and from 6 to 271×10^4 in 1973. Fewest propagules were trapped in May 1972 or July 1973 and the most in August 1972 or September 1973. Propagules of *F. moniliforme* varied from 50 to 3,200 per 20 cm^2 of corn leaf surface in the field; the fungus also was isolated from distal ends of silks. Air passing over corn obtained from a corn crib carried *Fusarium* spp. propagules, 95% of which were *F. moniliforme*. Circumstantial evidence for long-distance dissemination (300-400 km) of *Fusarium* spp. was obtained and 56% were propagules of *F. moniliforme*. Rain splash water collected over a corn field carried from 4 to 40 propagules of *F. moniliforme* per milliliter of water. From 3 to 50×10^4 propagules of *F. moniliforme* were detected per milliliter of leaf sheath water.

Additional key words: stalk rot, ear rot, aerobiology, epidemiology.

Fusarium moniliforme Sheld. emend. Snyd. & Hans., cause of both ear and stalk rots of corn (*Zea mays* L.), is commonly seedborne (5, 8, 11) but this source of inoculum does not seem likely to account for root or stalk infection (8, 11, 18). This fungus survives in corn stalk fragments in or on soil, and it can grow saprophytically in stalks if infection occurs first in living plants (16). It is seldom isolated from roots or soil and it makes up less than 5% of the colonies isolated from corn residues (22).

Ear infection probably develops from airborne or insect-borne (23) inoculum. Long-distance dissemination of *F. moniliforme* was reported by Ooka (17). Gregory et al. (6) observed that splash dispersal of *F. solani* and other fungi was efficient. Lukezic and Kaiser (13) reported airborne dispersal of *F. roseum* 'Gibbosum' in the absence of rain, and Nelson et al. (15) detected airborne propagules of *F. roseum* (three cultivars), *F. solani*, *F. oxysporum*, *F. tricinctum*, and *F. episphaeria*.

The objectives of this investigation were: to obtain quantitative estimates of airborne propagules of *F. moniliforme*, to study deposition of propagules on leaves and ears, to study airborne dispersal of propagules from infected kernels, and to study the effect of splashing rain on dispersal of propagules to corn leaf sheaths.

MATERIALS AND METHODS

Air samples were obtained with a six-stage, modified Andersen air sampler (1). The vacuum pump of the sampler was removed and attached to its base. An L-shaped bracket connected the pump base to the sampler base so that the sampling sieves were perpendicular to the ground. The standard entry cone on the sampler was removed, as suggested by Davies (2), and replaced with a simple retaining ring. This modified sampler was placed on a turntable fitted with a vane so that the sampler was pointed into the wind. A petri dish that contained 27 ml of pentachloronitrobenzene (PCNB) medium was placed in each stage of the sampler.

The sampler was located in a corn field 10 m from the edge of the field. Early in the season, the center of the sampling orifice was 76 cm above ground; as plants grew, the sampler was raised to 152 cm, and then to 203 cm above ground. To determine the optimum air sample, we evaluated samples of 28.3, 141.5, 283, 566, and 849 liters of air which were collected with the Andersen sampler. A sample size of 283 liters was selected for use in the ensuing studies. The sampler was in service several times during the day (1000 hours or 1200 hours) and not during rain.

The rain water splash traps were patterned after Waller (21). An analytical polyethylene funnel 100 mm in diameter and with a 100-mm-long stem was attached to the bottom of a 1-liter polyethylene bottle fitted with three, 6.4-mm-diameter screw eyes so that there was a 2-4 mm gap between the top of the funnel and the bottom of the bottle (Fig. 1). Small coil springs were attached to the screw eyes and to a shallow basket of 6.4-mm mesh hardware cloth. By this means, a 250-ml polyethylene collecting bottle was held in the trap.

To reduce the amount of direct rainfall collected, a roof was made by putting a rubber gasket over the neck of the bottle and inverting a 23-cm-diameter aluminum pie pan (with a 3.2-cm-diameter hole in the center) over the gasket and fastening this pan in place with a bottle cap. Standard laboratory clamps held the bottle to the field stand which consisted of a steel rod 3 m long driven into the ground and supported vertically by guy ropes.

Corn growth stages were determined by the Hanway (7) method on 40 plants/plot.

The isolation media used were either potato-dextrose agar (PDA) or pentachloronitrobenzene (PCNB)-peptone agar (14) supplemented with 50 mg chlortetracycline-HCl per liter (19). Usually, cultures were incubated for 5-7 days at 24 C and at 5,300 lux 12 hr/day.

Fusarium species were determined using the Snyder and Hansen system as described by Toussoun and Nelson (20).

RESULTS

Air dispersal in corn fields.—The distribution of *Fusarium moniliforme* for each stage of the sampler is presented in Table 1. This species made up 2 to 30% of the *Fusarium* spp., depending on the stage of the sampler. The propagules of *F. moniliforme* were either 2.1 μm or larger 80% of the time (Table 1). Colonies appeared also in stages 2, 3, and 4. Individual propagules were not identified in any of the sampler stages.

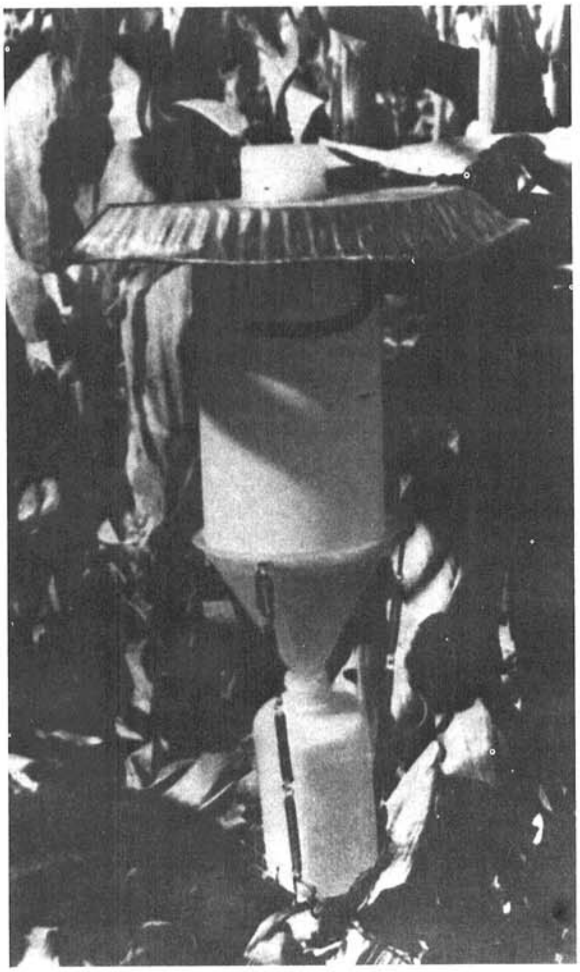

Fig. 1. Waller multidirectional splash trap attached to a stand in a corn field. Rain splashing from leaves strikes the upper polyethylene bottle and drains into the lower bottle.

In 1972 (238 air samples collected), the fewest propagules of *F. moniliforme* were trapped in May, and the most in August (Table 2). In 1973 (80 samples collected), the fewest propagules were collected in July and the most in September (Table 2). Thus, *F. moniliforme* was detected in lowest numbers during the period of active growth of corn (May-July) and in highest numbers when corn was maturing (August-September) and was more susceptible. Random isolates of *F. moniliforme* have proved to be pathogenic on seedlings.

To determine if spores of *F. moniliforme* were present on leaf surfaces, seven green leaves were chosen at random late in the season from corn plants in stage 9.5 (7). Five segments, each 20 cm^2, were selected from each leaf, added to 100 ml of sterile water and shaken for 30 sec. The wash water was then dispersed onto PCNB agar. The *F. moniliforme* colony counts on corn leaves from the seven samples varied from 50 to 3,200, and averaged 886 colonies per 20 cm^2 of surface. Therefore, about 83% of the *Fusarium* spp. population consisted of *F. moniliforme*.

To ascertain whether propagules were deposited on ears, six ears from each of four cultivars were selected from plants in stage 8 (early dent) and the distal 2.5 cm of 20 silks per ear were placed without surface disinfestation on PCNB agar. In addition, 12 complete silks were placed on agar. *Fusarium moniliforme* was isolated mainly from the distal ends of silks (85%) and only occasionally from their proximal ends (2%).

Air dispersal of conidia from corn ears.—Ears were collected from cribs near Lamberton, Minnesota, in March 1974. Kernels from seven seed lots were placed on PCNB agar to determine the percentage of kernels infected with *F. moniliforme*. Most of the kernels were infected (Table 3).

An apparatus was designed to permit a gentle air current to pass over kernels and thus test whether air passing over corn from cribs could dislodge conidia. The stem end of a 120-mm-diameter glass funnel was attached to the entry cone of an Andersen sampler with a piece of tubing. This funnel was inverted 2 cm above a 20-g portion of each sample layer, 150 mm in diameter. The impaction medium was PCNB agar. Air (4.7 liters) was drawn over the corn sample and into the Andersen sampler. Of the *Fusarium* colonies, 95% were *F. moniliforme* (Table 3). An occasional colony of *F. moniliforme* was detected in ambient air.

TABLE 1. Distribution of colonies of *Fusarium moniliforme* on each of six stages of the Andersen air sampler collected during 1970-1973

Stage of sampler[a]	Diameter of pores per stage (μm)	Colonies of *F. moniliforme* No.	% of total *Fusarium* spp.
1	7 - 11	73	30
2	4.7 - 7.0	30	12
3	3.3 - 4.7	53	22
4	2.1 - 3.3	40	16
5	1.1 - 2.1	6	2
6	.65 - 1.1	43	18

[a]Stages in sampler numbered from top (No. 1) to bottom (No. 6).

Long distance dispersal by wind.—Wind-blown soil was collected from a thin layer deposited on the snow surface during a winter dust storm (blizzard) of 10-11 January 1975. The Earth Resources Technology Satellite imagery (W. H. Anderson, National Park Service, Mississippi) was useful in identifying the probable origin of the soil. An area near Bemidji, Minnesota (320 km northwest of St. Paul), in the direction of the prevailing wind, was relatively free from snow prior to the blizzard. Dust and snow were reported in North and South Dakota during this storm, but the only Minnesota station that reported blowing dust was in the region from Alexandria to St. Paul. The wind pattern at about this time could have brought the dust, reported in Alexandria, to St. Paul (E. L. Kuehnast, State Climatologist, University of Minnesota, *personal communication*).

The average population of *Fusarium* species from 24 samples was estimated at 1,423 ± 149 propagules/g soil, based on the dilution plate method and using PCNB agar. Of 432 random isolates, *F. moniliforme* made up 56%; *F. oxysporum* Schl. emend. Snyd. & Hans., and *F. roseum* (Lk.) emend. Snyd. & Hans. each accounted for 11%. *Fusarium episphaeria* (Tode) emend. Snyd. & Hans. accounted for 7%, *F. solani* (Mart.) App. & Wr. emend. Snyd. & Hans. 4%, and *F. tricinctum* (Cda.) emend. Snyd. & Hans. 1% of the colonies. Ten percent of the colonies were other fungi.

At another location, in a wooded city park, 44 samples were assayed for *Fusarium* spp., but no colonies of *F. moniliforme* were detected. Instead, *F. roseum* accounted for 38%, *F. solani* 31%, *F. oxysporum* 23%, and *F. episphaeria* 8% of the colonies. In general, fewer colonies of *Fusarium* appeared in the park than in a nonwooded field even though each location had a heavy snow cover. We estimated that this windblown soil traveled 300-400 km and concluded that these *Fusarium* species originated from the distant source.

Rain dispersal of fungus.—The importance of rain splash dispersal by *F. moniliforme* was investigated with the Waller multidirectional splash trap (21) during the 1973 and 1974 growing seasons. The splash traps were attached to a mast so that the middle of the collecting surface was at 50, 100, 150, and 200 cm above the ground. After a rain of at least 0.6 mm, collection vessels were removed, the sample volumes measured, and the dilution plates prepared with PCNB agar. The results are shown in Table 4.

Propagules of *F. moniliforme* were dispersed to neighboring plants by rain splash (Table 4). Moreover, the increase in propagule number as corn plants matured was similar to the increase in number of propagules trapped in the air. When the values from the splash sample of 1973 (Table 4) held in common with the air samples of 1973 (Table 2) for June, July, August, and September were correlated, the resultant correlation coefficient ($r = +0.99$) was significantly different from zero (at $P = 0.05$). Therefore, propagules in air or in splashing rain water reflect similar trends in production.

Following one rainfall of 1.37 cm, 1-ml samples of rain water were pipetted from the leaf sheaths of 80 plants (20 plants for each of four cultivars). The samples from each cultivar were bulked and assayed by serial dilution on PCNB agar. The populations of *F. moniliforme* varied from 3 to 50×10^4 propagules/ml of water trapped between the leaf sheath and the stalk. Thus, splashing rain can disperse propagules from plant to plant or wash them from leaves into sheaths.

DISCUSSION

Fusarium moniliforme frequently has been isolated from kernels in Minnesota (11, 18, 23) and in nearby states (5, 8), and from stalks (3, 9, 10), especially when bruised by hail (12). The source of this inoculum is not known with certainty. Some inoculum is probably carried by insects present in dropped ears lying on the ground from previous seasons (23), and some may be present in corn residues but not in appreciable amounts (16, 22). Doupnik et al. (4) reported a lower incidence of stalk rot in sorghum (caused by *F. moniliforme*) after 3 yr of no tillage than after conventional tillage. Their explanation for less stalk rot with no tillage relates partly to less stress on plants because of the higher soil moisture and lower soil temperature effected by crop refuse and not to the amount of inoculum present in wheat or sorghum residues. Similarly, the incidence of plants infected with *F. moniliforme* (76%) was higher in the 12 sampled counties of southern Minnesota in the dry summer of 1976 (9) than the incidence (21%) in the 14 counties sampled in 1973 (10). Conventional tillage is usual in these counties.

Although *F. moniliforme* may not be abundant in crop residues at the end of the growing season (16, 22), it may be present in sufficient amounts or may multiply rapidly enough during the growing season on crop residues, leaf surfaces, or in rain water trapped in leaf sheaths, to build up its inoculum potential. From one or more of these sources, wind and rain could disseminate propagules to ears or wash them into sheaths where infection can occur through nodes of stalks.

TABLE 2. Numbers of colonies of *Fusarium moniliforme* per sample per liter of air sampled in corn fields in 1972 and 1973

Month	No. samples[a]		10^4 colonies/ml		Colonies/sample	
	1972	1973	1972	1973	1972	1973
April	28	18	38	43	1.1	1.2
May	77	6	8	88	0.2	2.5
June	69	16	27	38	0.7	1.1
July	25	6	31	6	0.9	0.2
August	19	25	78	52	2.2	1.5
September	20	9	27	271	0.8	7.2

[a]Each sample equals 283 liters of air.

TABLE 3. Percentage kernels infected with *Fusarium* spp. and number of *Fusarium* spp. per stage of the Andersen air sampler collected when air was passed over corn kernels from corn cribs

Sample no.	*Fusarium*-[a] infected kernels (%)	*Fusarium* spp. colonies/stage[b] (no.)					
		1	2	3	4	5	6
1	100	39	31	27	38	31	31
2	100	20	16	10	26	21	16
3	100	23	17	21	0	0	0
4	100	30	31	29	31	26	35
5	90	0	0	0	0	0	0
6	100	0	0	0	0	0	0
7	70	0	0	2	0	2	0

[a]Of *Fusarium* spp. obtained, 95% were *F. moniliforme*.
[b]Number of colonies per stage (top is no. 1) for 4.7 liters of air and counted on pentachloronitrobenzene agar plates.

TABLE 4. Numbers of colonies of *Fusarium moniliforme* per milliliter of splashing rain water collected in the Waller multidirectional splash trap set in a cornfield

Month of sampling	Colonies/ml[a] splashing rain	
	1973	1974
June	12.8	
July	8.6	12.0
August	11.6	4.3
September	40.0	22.4
October		24.0

[a]Average of two dilutions per sample and three plates per dilution.

Propagules impacted on agar surfaces were examined but they were difficult to identify to spore type because of associated debris. In the past decade we have not observed perithecia from *F. moniliforme* in the field even though DeVay et al. (3) reported their occurrence in 1956. Ooka (*unpublished*) collected 133 isolates and A. Tjokrosudarmo (*unpublished*) collected 102 isolates of *F. moniliforme* and attempted crosses of them in all possible combinations, but no perithecia resulted. Thus, we have no evidence that ascospores were being disseminated.

If propagules can be found in soil carried by wind in winter blizzards, it seems possible that wind might blow fragments of *Fusarium*-infected crop residues in soil from one field to another in summer. Conventional tillage is common in the state and may lead to more wind-blown dust than is likely with no or minimum tillage. Also, winds could carry inoculum from corn cribs to nearby fields.

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