The Effect of Postharvest Fungicide Application on Storage Fungi of Corn During Ambient Air Drying and Storage

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ABSTRACT

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Corn grain was treated immediately after harvest with the fungicides benomyl (0, 1, 5, and 10 $\mu g/g$), thiabendazole (0, 5, 10, and 20 $\mu g/g$), and A9248 (0, 5, 10, and 20 $\mu g/g$) in 1984, and with thiabendazole (0, 10, and 20 $\mu g/g$) and A9248 (0, 5, 10, and 20 $\mu g/g$) in 1985 to determine the effect of the fungicides on infection by storage fungi during ambient air drying and storage. After treatment, the grain was augured into modified grain bins and dried with ambient air. The incidence of storage fungi was determined following plating of kernels on malt salt agar. Fungicide treatments reduced the incidence of Penicillium species, and in some cases Aspergillus species, when compared to the nontreated control. The use of low rates of fungicides offers an additional control of storage fungi that can be integrated into currently used control techniques.

Additional keywords: maize, Zea mays, low-temperature drying

Following harvest, corn grain is subject to infection and damage by numerous fungi, primarily Aspergillus species and Penicillium species (29). The incidence and severity of damage caused by these fungi are dependent upon a number of factors including storage temperature, grain moisture, relative humidity of air in the grain mass, fungal species present, levels of preharvest infection, and mechanical damage to the kernels.

Since Aspergillus and Penicillium species actively grow at grain moistures greater than 16%, high-temperature drying of corn to less than 15% moisture immediately after harvest is commonly used in the midwestern United States to control these storage fungi (35). Grain is dried to 14% moisture or less if it is to be stored through the spring and summer. Although high-temperature drying may prevent the growth of fungi, it can be expensive because of high energy consumption (31); and it causes stress cracking of kernels, which can result in greater amounts of physical damage (broken corn) each time the grain is handled (33). Additionally, corn grain that is dried to lower moistures is more susceptible to physical damage from the mechanical handling used in marketing channels (11). Broken kernels can serve as sites for the penetration of storage fungi and are not desirable for some types of corn processing.

Ambient air drying (low-temperature drying) is preferable to high-temperature drying because it requires less energy (31) and does not cause excessive stress cracking of kernels (3,17). However, ambient air drying has not been widely adopted in the midwest because normal climatic conditions can result in slow drying rates that permit grain deterioration because of fungal growth (9). Additionally, because of the slow drying rate, it is not recommended when grain moisture is high at harvest (2). Any reliable method of controlling storage fungi could increase the use of ambient air drying.

A number of different methods to chemically control storage fungi have been tested previously. In 1947, Milner et al (19) tested more than 100 compounds for their fungicidal activity on stored wheat. They concluded that no compound was consistently effective and safe, even though some slowed the rate of fungal growth. Propionic acid has been used as a preservative in stored corn (4,12-16,28), sorghum (14,24,28), barley, oats, wheat (14), and forages (12). Propionic acid treatment has been shown to increase the allowable time for completing low-temperature drying of corn, thus allowing for a higher harvest moisture (32). Although propionic acid-treated grain may enhance feeding efficiency in cattle (13), it destroys grain germinability (24), is corrosive to bins (3), and is not suitable for direct human consumption (24). Ammonia has also been tested as a grain preservative for corn (5,12,26) and forages (12). While it is an effective

control method, ammonia treatment results in discolored grain with a residual ammonia odor (5). Formaldehyde (23), sulfur dioxide (8,9), and sorbic acid (7,28) also have been considered as potential grain protectants. While all three have various degrees of effectiveness, each has particular disadvantages. Formaldehyde treatment of wheat destroys the baking quality of wheat flour and results in a depressed growth rate, feed intake, and feed-efficiency ratio in chicks (23). Sulfur dioxide reduces grain germinability and is corrosive to galvanized steel (8,9). Sorbic acid, while very effective in laboratory tests (7,28), was not effective in actual storage tests with wheat (7).

Because storage mold fungi do not usually penetrate and infect kernels before harvest (27,34), fungicides applied at harvest may be useful as grain protectants during ambient air drying, grain handling, and storage of corn grain. Within the last 20 years, benzimidazole fungicides with the potential to inhibit storage molds have been developed and marketed (10). Several laboratory studies indicate the efficacy of fungicides for control of storage fungi. Experiments by Niles with barley samples treated with different fungicides suggested that several compounds, particularly benomyl, may be effective as grain protectants (25). Niles also suggested that these compounds may be much more effective with improved application methods. Work with corn has shown that several fungicides, including benomyl and thiabendazole, prevent infection by storage fungi and effectively protect seed germinability (20,21,22). Soybean oil, with and without thiabendazole, has been shown to reduce infection by storage fungi (18). The fungicide iprodione (Rovral, Rhone-Poulenc Ag Co.) has also been shown to reduce the rate of corn grain deterioration as measured by CO_2 production (1,38). Our preliminary experiments with benomyl, thiabendazole, and A9248 treated corn, stored at 90% RH and 26 C, confirm the effectiveness of these compounds as potential grain protectants (36). Subsequent studies in grain bins have shown the effectiveness of thiabendazole (37). The objective of this research was to determine the effect of low rates of three fungicides on infection of corn kernels by *Penicillium* species and *Aspergillus* species during ambient air grain drying and storage under conditions similar to those in the midwestern United States.

MATERIALS AND METHODS

Experiments were done in two modified, commercially available grain bins at the Agronomy-Plant Pathology South Farm, Urbana. Each bin (5.7 m eave height, 4.6 m diameter) is equipped with a drying floor and a fan capable of airflows through the grain mass of 0.13

Fig. 1. Experimental bin with sampling ports that allow for samples to be taken from various grain depths. The 16 wedge-shaped compartments in the bin accommodate various experimental treatments.

m³/min/quintal (1.2 ft³/min/bu) when the bin is full of grain. Bins are divided into 16 wedge-shaped compartments (experimental units) to accommodate various treatments. Each compartment also has sampling ports so that samples can be taken from the side of the bin (Fig. 1). In these experiments, samples were taken from the bottom, middle, and top, which were 1.2, 2.4, and 3.6 m above the grain bin drying floor.

In 1984, three experiments were done simultaneously. In experiment one, benomyl (Benlate, 50 WP, E. I. du Pont de Nemours & Co., Wilmington, DE) was tested at 0, 1, 5, and 10 µg/g (a.i. fungicide per dry weight of grain). In experiment two, thiabendazole (Mertect 340F, Merck Chemical Co., MSD AgVet Division, Rahway, NJ) was tested at 0, 5, 10, and 20 µg/g (a.i. fungicide per dry weight of grain). In experiment three, A9248 (diiodomethyl p-tolysulfone, 50 WP, Abbott Laboratories, North Chicago, IL) was tested at 0, 5, 10, and 20 µg/g (a.i. fungicide per dry weight of grain). Experiments one and two were done in the same bin. In 1985, thiabendazole and A9248 were tested in two separate bins. Thiabendazole was tested at 0, 10, and 20 µg/g, and A9248 at the same rates as 1984. All experiments were arranged as a randomized complete block with two replicates. Corn grain (hybrid B73 × LH38) was harvested at approximately 24.5% grain moisture on

9 October 1984 for experiments one and two. Poor yields prevented us from obtaining enough grain for all three experiments from the same field. For experiment three, a field of the same hybrid at approximately 22.5% grain moisture was harvested on 10 October 1984. In 1985, grain of the same hybrid was harvested from a single field on 1 October at approximately 23.0% grain moisture.

Fungicide treatments were applied as grain was augured into the bins. Applications of fungicides were done with a Gustafson DD-21 metering pump equipped with two 8002E TeeJet nozzles mounted onto a Ortho Propionic Acid Treater. Approximately 466 ml of water per quintal was used as a carrier for the fungicide. Controls were treated with water.

Grain samples (3–7 kg) were taken before treatment and from the three sampling levels immediately after treatment, weekly for the first 10 wk and biweekly until week 40 in 1984, and weekly for 11 wk and biweekly until week 41 in 1985. Grain moistures were determined with a Steinlite Model SS250 moisture meter. Fifty whole, randomly selected kernels from each sample were surface sterilized in a 1.575% sodium hypochlorite solution for one minute and plated 10 to a plate on malt salt agar. After 1 wk at room temperature (approximately 23 C), the number of kernels infected with a particular fungi was recorded.

The number of kernels from which Penicillium species were isolated was converted to a percentage. The number of kernels from which different Aspergillus species (A. flavus Link:Fr., A. glaucus Link:Fr. group, and A. niger Tiegh.) were isolated was summed for the total Aspergillus species. The area under the

disease progress curve (AUDPC) was calculated (30) from data of the percent Penicillium species and total Aspergillus species for each sampling level and averaged over the three sampling levels for each replicate. AUDPC values were also calculated for the grain moisture of each treatment at each sampling level and for treatments averaged over the three levels. AUDPC values of the average grain moisture of all treatments at each sampling level were calculated to compare the average moisture of the three sampling levels. Analysis of variance was then used to detect significant differences among treatments for percent Penicillium species, total Aspergillus species, and grain moisture for each sampling level, the average of the three levels, and the average of all treatments at each level.

RESULTS

Grain Moisture. AUDPC values for grain moisture of the various treatments were not significantly different from each other at any sampling level or combined over levels in any of the five experiments (AUDPC values not shown). When AUDPC values were calculated for the average of all treatments in each experiment at individual sampling levels, there were significant differences among moistures at each level in all five experiments. In all experiments, grain from the lower sampling levels dried more rapidly and maintained a lower grain moisture than grain from the middle or top levels. Grain at the top level was always significantly higher in moisture than grain from the middle or bottom.

In the 1984 benomyl and thiabendazole experiments, grain moistures were similar because experiments were done in a bin with a common fan and with corn from one field (Fig. 2). Grain moistures at the bottom sampling level were reduced to an average of 14.8% with 3 wk of continuous aeration with ambient air following harvest. Grain moistures at this level ranged from an average of 14.6 to 15.5% for the duration of the experiment. Grain moistures at the middle sampling level were reduced to 18.8% by week 3. Intermittent operation of the drying fan until week 7 further reduced the grain moisture to an average of 15.3%. Moisture increased from week 10 to 20, possibly from moisture migration. Grain moisture then gradually declined to 15.0% at week 32 as the drying fan was operated for brief periods in weeks 24 and 28. Grain moistures in the top sampling level were reduced to an average of 20.4% by week 3 and to an average of 17.4% by week 7. Grain moistures then increased from week 10 to 20 and gradually declined to 15.9% by week 30.

In the 1984 A9248 experiment, grain moistures were lower than in experiments one and two (Fig. 2). Moistures at the lowest sampling level were reduced
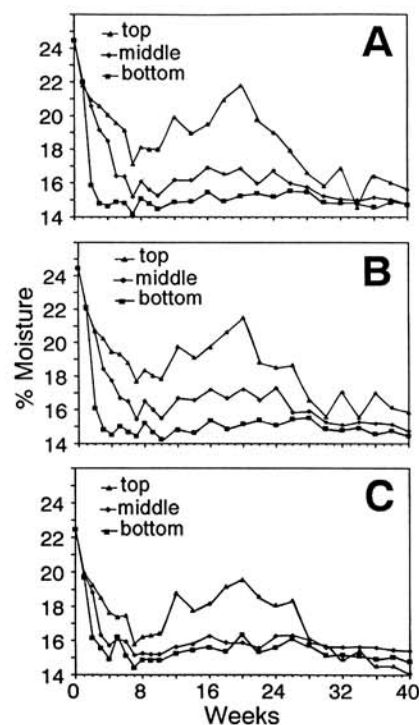

Fig. 2. Percent corn grain moisture from three bin sampling levels averaged over two replicates and four treatments. Bottom, middle, and top levels were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively. (A) = 1984 benomyl experiment, (B) = 1984 thiabendazole experiment, and (C) = 1984 A9248 experiment.
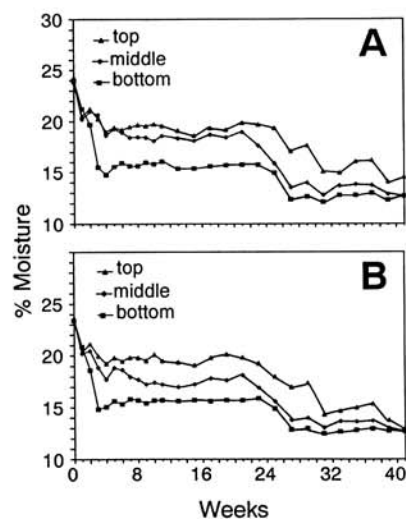

Fig. 3. Percent corn grain moisture from three bin sampling levels averaged over two replicates and all treatments. Bottom, middle, and top levels were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively. (A) = 1985 thiabendazole experiment and (B) = 1985 A9248 experiment.

to an average of 15.6% after 3 wk of continuous ambient air aeration following harvest. Intermittent aeration to week 7 further lowered grain moisture to an average of 14.5%. Grain moistures at this level then ranged from 14.5 to 16.4% through the duration of the experiment. At the middle sampling level, grain moistures were reduced to an average of 16.3% at week 3. By week 7, the grain had dried to an average of 15.0%. Grain moisture in this level then ranged from 15.0 to 16.2% until the conclusion of the experiment. In the top sampling level, grain moistures were reduced to an average of 18.5% by week 3 and to an average of 15.8% by week 7. As in the benomyl and thiabendazole experiments, grain moistures increased from week 10 to 20. Operation of the drying fans in weeks 24 and 28 gradually reduced grain moistures in the top level to an average of 14.9% at week 32.

In the 1985 A9248 experiment, grain moistures at the bottom sampling level were reduced to an average of 15.0% with 4 wk of continuous aeration (Fig. 3). Moistures at this level ranged from an average of 15.0 to 15.8% until week 19. Continuous aeration from week 21 to week 27 reduced the moisture to an average of 12.8% for the duration of the experiment. Grain moistures at the middle sampling level were reduced to an average of 17.7% by week 4. Moistures at this level ranged from an average of 17.4 to 18.8% until week 19. Continuous aeration from week 21 to 27 reduced the moisture to an average of 13.4% for the duration of the experiments. Grain moisture at the top sampling level was reduced to 19.2% by week 4. Moistures at this level ranged from an average of 19.2 to 20.1% until week 19. Moisture was reduced to 16.9% by week 27. Additional aeration between weeks 27 and 42 further reduced moisture.

In the 1985 thiabendazole experiment, grain moistures at the bottom sampling level were reduced to an average of 14.7% after 4 wk of continuous aeration (Fig. 3). Moistures at this level ranged from an average of 14.7 to 16.0% until week 19. Continuous aeration from week 21 to week 27 reduced the moisture to an average of 12.3% for the duration of the experiment. Grain moistures at the middle sampling level were reduced to an average of 18.6% by week 4. Moistures at this level ranged from an average of 18.0 to 19.2% until week 19. Continuous aeration from week 21 to 27 reduced the moisture to an average of 13.5% for the duration of the experiment. Grain moisture at the top sampling level was reduced to an average of 19% by week 4. Grain moistures at this level ranged from an average of 19.0 to 19.7% until week 19. Moisture was reduced to 17.1% by week 27. Additional aeration between weeks 27 and 42 further reduced moisture.

Infection by *Penicillium* species. In all

experiments, the percentage of kernels from which *Penicillium* species were isolated increased for the first several weeks of the experiment in the control treatments. Incidence of *Penicillium* species in the control treatment was higher in the benomyl and thiabendazole experiments in 1984 than in the A9248 experiment or in the two experiments in 1985 (Figs. 4 and 5).

In the 1984 benomyl experiment, the percent kernels from which *Penicillium* species were isolated in the control treatment increased rapidly at all sampling levels to an average of 66.7% by week 8. The average then varied from 47 to 80.7% for the remainder of the experiment (Fig. 4). At the bottom sampling level, the percent kernels from which *Penicillium* species were isolated averaged 55% by week 8 and varied from 30 to 62% for the remainder of the experiment. At the middle sampling level, the average was 72% at week 8 and varied from 42 to 89% for the remainder of the experiment. At the top sampling level, the average was 73% at week 8 and varied from 67 to 93% for the remainder of the experiment. With the 1 $\mu g/g$ rate, the average of all sampling levels was highest at week 18 with an average of 31.3%. With the 5 $\mu g/g$ rate, the averages were below 10% until week 38. With the 10

$\mu g/g$ rate, averages were less then 5% until week 36. The AUDPC values of percent *Penicillium* species for all rates at each sampling level and averaged over the three sampling levels were significantly less than the control (Table 1). The AUDPC values for the three rates of benomyl were not significantly different from each other at the bottom and middle sampling levels or averaged over the three levels. At the top sampling level, where the incidence of *Penicillium* species was greatest, the 5 and 10 $\mu g/g$ rates were more effective than the 1 $\mu g/g$ rate.

In the 1984 thiabendazole experiment, the percent kernels from which *Penicillium* species were isolated in the control also increased rapidly for the first 8 wk to an average of 48%. As with the benomyl experiment, the percent kernels from which *Penicillium* species were isolated was less at the bottom sampling level (average of 29%) than at the middle and top levels (51 and 64%, respectively). After week 8 the percent kernels from which *Penicillium* species were isolated varied from 6 to 80% at the bottom sampling level, 22 to 75% at the middle, and 53 to 91% at the top. With the 5 and 10 $\mu g/g$ rates, the highest average percent *Penicillium* species of all sampling levels was at week 18 with 32.7 and 33.3%, respectively. The 20 $\mu g/g$ rate had the lowest average percent, which was less than 12% at all sampling times. The AUDPC values of percent *Penicillium* species for all rates at each sampling level and averaged over levels were significantly less than the control. Rates of thiabendazole were not significantly different at the bottom and middle sam-
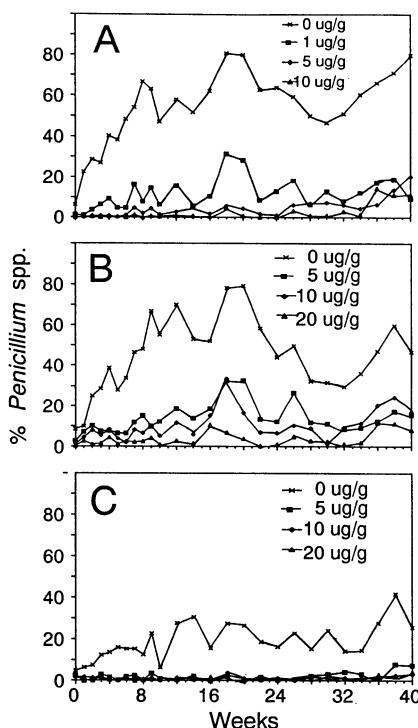
Fig. 4. Percent kernels (n = 50) from which *Penicillium* species were isolated averaged over two replicates and three bin sampling levels. Bottom, middle, and top levels were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively. Treatments consisted of untreated control and various rates of fungicide applied immediately after harvest. (A) = 1984 benomyl experiment, (B) = 1984 thiabendazole experiment, and (C) = 1984 A9248 experiment.

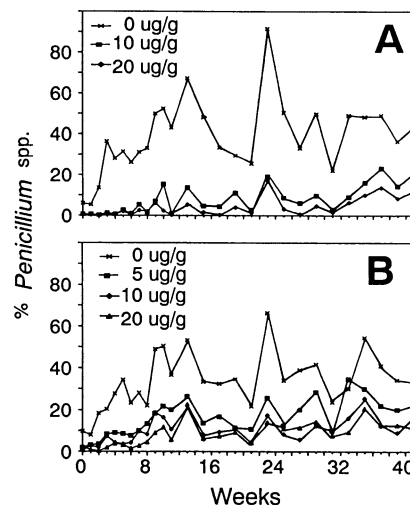Fig. 5. Percent kernels (n = 50) from which *Penicillium* species were isolated averaged over two replicates and three bin sampling levels. Bottom, middle, and top levels were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively. Treatments consisted of untreated control and various rates of fungicide applied immediately after harvest. (A) = 1985 thiabendazole experiment and (B) = 1985 A9248 experiment.

pling level, but the 20 μg/g rate was more effective than the 5 μg/g rate at the top level. Averaged over all levels, there were significant differences among rates, with higher rates being more effective.

In the 1984 A9248 experiment, there was less Penicillium than in the benomyl or thiabendazole experiments. In the control, percent Penicillium species averaged over all sampling levels was below 30% until week 38. The highest percent occur-

red at the top sampling level, with a high of 74% at week 38. The A9248 treatments reduced the percent to less than 10% for all rates at all sampling levels. The AUDPC values of the three rates were significantly less than the control at all sampling levels and averaged over levels. The three rates were not significantly different from each other.

The percent Penicillium species in the 1985 thiabendazole experiment was less

than the 1984 experiment (Fig. 5). The percent kernels from which Penicillium species were isolated, averaged over all sampling levels, increased to 67.3% by week 13. It then varied from 22.0 to 91.7% for the duration of the experiment. As with previous experiments, Penicillium species were isolated from fewer kernels at the bottom sampling level than at the middle or top levels. With the 10 μg/g thiabendazole treatment, the per-

Table 1. The area under disease progress curve (AUDPC)[a] for incidence of Penicillium spp. and Aspergillus spp. on corn grain treated with different rates of benomyl, thiabendazole, and A9248 (1984 experiments)

Fungicide	Rate	% Penicillium spp.[b] (AUDPC)				Total Aspergillus spp.[c] (AUDPC)			
		B[d]	M[e]	T[f]	A[g]	B	M	T	A
Benomyl	0 μg/g	1,695	2,304	2,807	2,268	361	518	822	567
	1 μg/g	147	415	951	504	109	141	423	225
	5 μg/g	18	148	381	182	122	238	249	203
	10 μg/g	11	29	262	100	50	50	167	89
P[h]		0.027	0.007	<0.001	0.003	0.111	0.140	0.082	0.105
LSD (k-ratio = 100)[i]		858	691	366	478				
Thiabendazole	0 μg/g	1,199	1,867	2,637	1,901	327	444	679	483
	5 μg/g	172	522	1,110	601	151	134	274	186
	10 μg/g	150	473	725	449	215	313	434	321
	20 μg/g	66	132	292	163	141	182	369	231
P[h]		<0.001	0.009	0.003	<0.001	0.187	0.105	0.263	0.135
LSD (k-ratio = 100)		160	544	511	112				
A9248	0 μg/g	395	644	1,376	805	105	248	463	272
	5 μg/g	43	40	172	85	33	43	180	85
	10 μg/g	17	28	103	49	14	26	82	40
	20 μg/g	24	33	77	44	8	14	22	14
P[h]		0.018	0.038	0.033	0.031	0.036	0.003	0.093	0.014
LSD (k-ratio = 100)		168	365	718	415	52	55		97

[a] AUDPC = E[Yi + 1 + Yi)/2] [Xi + 1 − Xi]; where Yi = the proportion of infected kernels at the ith observation; Xi = week of the ith observation; n = total number of observations; and i = the week of rating.
[b] Based on 50 kernels in each of two replicates.
[c] Sum of Aspergillus spp. (A. flavus, A. glaucus, A. niger) from 50 kernels in each of two replicates.
[d] Bottom sampling level, 1.2 m from the drying floor.
[e] Middle sampling level, 2.4 m from the drying floor.
[f] Top sampling level, 3.6 m from the drying floor.
[g] Averaged over all three sampling levels.
[h] Probability of greater F statistics for rates from one-way analyses of variance.
[i] Waller Duncan Bayesian LSD test.

Table 2. The area under disease progress curve (AUDPC)[a] for incidence of Penicillium spp. and Aspergillus spp. on corn grain treated with different rates of benomyl, thiabendazole, and A9248 (1985 experiments)

Fungicide	Rate	% Penicillium spp.[b] (AUDPC)				Total Aspergillus spp.[c] (AUDPC)			
		B[d]	M[e]	T[f]	A[g]	B	M	T	A
Thiabendazole	0 μg/g	1,047	1,646	2,357	1,683	102	104	209	139
	10 μg/g	126	305	612	348	59	71	95	75
	20 μg/g	101	165	296	187	53	68	105	75
P[h]		0.008	0.011	0.007	0.006	0.848	0.377	0.007	0.341
LSD (k-ratio = 100)[i]		198	341	373	251			21	
A9248	0 μg/g	673	1,523	2,167	1,454	121	118	162	134
	5 μg/g	367	563	1,232	721	27	33	199	86
	10 μg/g	177	467	706	450	19	22	50	30
	20 μg/g	180	245	744	390	9	20	39	23
P[h]		0.126	0.046	0.041	0.043	0.004	0.070	0.031	0.002
LSD (k-ratio = 100)			721	831	609	28		89	24

[a] AUDPC = E[Yi + 1 + Yi)/2] [Xi + 1 − Xi]; where Yi = the proportion of infected kernels at the ith observation; Xi = week of the ith observation; n = total number of observations; and i = the week of rating.
[b] Based on 50 kernels in each of two replicates.
[c] Sum of Aspergillus spp. (A. flavus, A. glaucus, A. niger) from 50 kernels in each of two replicates.
[d] Bottom sampling level, 1.2 m from the drying floor.
[e] Middle sampling level, 2.4 m from the drying floor.
[f] Top sampling level, 3.6 m from the drying floor.
[g] Averaged over all three sampling levels.
[h] Probability of greater F statistics for rates from one-way analyses of variance.
[i] Waller Duncan Bayesian LSD test.

cent *Penicillium* species averaged over both replicates and all sampling levels was as high as 23% at week 37; and at the 20 μg/g rate, it was as high as 17.3% at week 23. The AUDPC values for percent *Penicillium* species for the thiabendazole treatment were significantly lower than for the control at each sampling level and averaged over levels (Table 2). The rates were not significantly different at any level or averaged over levels.

In the 1985 A9248 experiment, the percent *Penicillium* species in the control averaged over all sampling levels increased to 53.3% by week 13. It then varied from 21.7 to 66.3% for the remainder of the experiment. At week 13, fewer isolations occurred at the bottom than at the middle or top sampling levels, with 31, 51, and 71%, respectively. With the A9248 treatments, the percent was lower than the control, particularly at the 20 μg/g rate. The AUDPC values for percent *Penicillium* species at the bottom sampling level were not significantly different. The AUDPC values of the A9248 treatments were significantly lower than the control at the middle and top sampling levels as well as averaged over all levels. There were no significant differences among the rates of A9248.

Infection by *Aspergillus* species. The effect of fungicides on *Aspergillus* species was not as dramatic as with *Penicillium* species. Isolations of *Aspergillus* species were low until later in the experiments with the lower grain moistures and warmer temperatures in the spring and summer (Figs. 6 and 7). In general, treatment with fungicides resulted in fewer isolations of all *Aspergillus* species, with *A. glaucus* being the most frequently isolated. In the 1984 benlate and thiabendazole experiments, the AUDPC values of total *Aspergillus* species were not significantly different. In the 1984 A9248 experiment, the AUDPC values of fungicide treated samples were significantly different from the control at the bottom sampling level, the middle level, and averaged over all three levels. The rates did not differ (Table 1).

In the 1985 experiments, *Aspergillus* species were not frequently isolated until after week 32. The AUDPC values of thiabendazole treatments were significantly different from the control only at the top sampling level, where *Aspergillus* species were isolated in higher numbers (Table 2). With A9248, the AUDPC values of treated samples were significantly lower than the control at the bottom sampling level, the top level, and averaged over all levels.

DISCUSSION

The three fungicides tested did control infection of kernels by *Penicillium* species and in some experiments by *Aspergillus* species. The higher incidence of *Penicillium* species in the 1984 benomyl

and thiabendazole experiments was likely due to the higher harvest moisture in those experiments. The percent kernels from which *Penicillium* species were isolated was much less in the 1984 A9248 experiment, where harvest moisture was 22.5% compared to 24.5% in the benomyl and thiabendazole experiments. In 1985, corn was harvested at an average of 23.0% moisture, and the percent kernels from which *Penicillium* species were isolated was slightly lower than in the benomyl and thiabendazole experiments in 1984; however, it was higher than in A9248 experiment in 1984.

Aspergillus species were isolated more frequently later in the experiments than were *Penicillium* species. This was probably due to the lower grain moisture and higher temperature in the spring and summer, which favor the growth of *Aspergillus* species, particularly *A. glaucus* (29). Significant control of *Aspergillus* species did not occur in several of the experiments. The fungicide A9248 provided significant control of *Aspergillus* species in both years; however, in both experiments with A9248, the incidence of *Penicillium* species was lower than in other experiments. High levels of *Peni-*
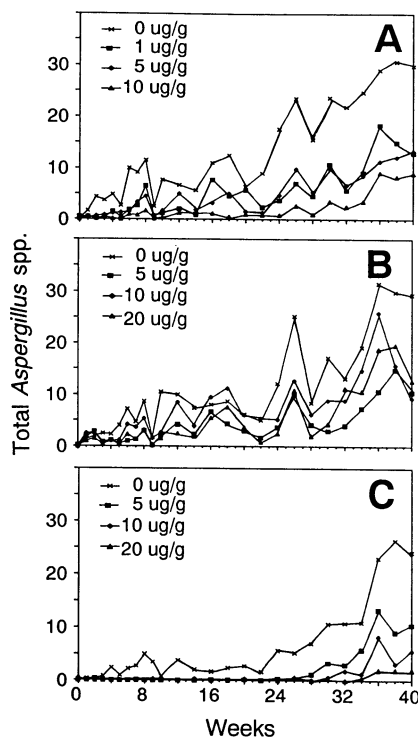
Fig. 6. Effect of fungicide application on *Aspergillus* species. Total is the sum of the number of kernels (n = 50) from which different *Aspergillus* species (*A. glaucus, A. niger,* and *A. flavus*) were isolated averaged over two replicates and three bin sampling levels. Bottom, middle, and top levels were 1.2, 2.4, and 3.5 m above the grain bin drying floor, respectively. Treatments consisted of untreated control and various rates of fungicide applied immediately after harvest. **(A)** = 1984 benomyl experiment, **(B)** = 1984 thiabendazole experiment, and **(C)** = 1984 A9248 experiment.

cillium species in some experiments may have made kernels more susceptible to *Aspergillus* species, which made the fungicides appear ineffective. It is also possible that fungicides had degraded later in the experiments and were not as effective.

There were dramatic differences in storage fungi activity at different sampling levels because of the differences in grain moisture between the levels. Fungicide rates were usually not significantly different among sampling levels. However, in the 1984 benomyl and thiabendazole experiments, rates of the fungicides were significantly different at the top sampling level, where the incidence of *Penicillium* species was the greatest. It is likely that the lower rates of fungicide would provide effective control with lower harvest moisture and more rapid drying. At higher harvest moisture and slow drying, only higher rates of fungicide would provide adequate control.

One major disadvantage of low-temperature drying is the recommended grain moisture at harvest (2). These recommendations are based on the average relative humidities and temperatures of air at different times in the fall. The recommended harvest moisture is lower early in the fall (September) because of the warmer temperatures, which favor fungi. The recommended harvest moisture is also lower by mid-November, because the drying potential of the air (cool and wet) will usually be less. Recommendations are established to allow for
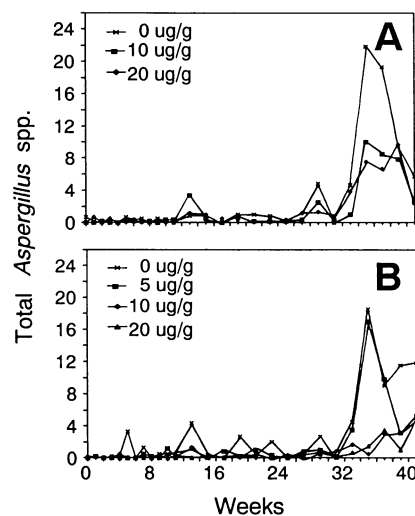
Fig. 7. Effect of fungicide application on *Aspergillus* species. Total is the sum of the number of kernels (n = 50) from which different *Aspergillus* species (*A. glaucus, A. niger,* and *A. flavus*) were isolated averaged over two replicates and three bin sampling levels. Bottom, middle, and top levels were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively. Treatments consisted of untreated control and various rates of fungicide applied immediately after harvest. **(A)** = 1985 thiabendazole experiment and **(B)** = 1985 A9248 experiment.

successful drying without excessive damage by fungi only 9 out of 10 yr. At airflow rates produced by the fans on our bins, the recommended harvest moisture on 10 October would be 21% (1984 experiments) and on 1 October would be 20.5% (1985 experiments). Harvest moistures in our experiments exceeded these recommendation by 3.5% with the 1984 benlate and thiabendazole experiments, by 1.5% with the 1984 A9248 experiment, and by 2.5% with the 1985 experiments. These slight differences in harvest moisture are important. For example, on 1 October the recommended airflow would be 0.11 m^3/min/quintal (1.0 ft^3/min/bu) for corn harvested at 20% grain moisture and 0.22 m^3/min/quintal (2.0 ft^3/min/bu) for corn harvested at 22% grain moisture. A 2% increase in grain moisture at harvest would result in a doubling of the recommended airflow. In general, the airflow in our bins is half or less the recommended cfm for the harvest moistures used in our experiments. Recommendations would also include drying of all grain to 14% by spring, which did not occur in our experiments. The low recommended harvest moisture is a serious disadvantage of low-temperature drying, because allowing grain to dry in the field increases stalk rot and subsequent stalk lodging, resulting in nonharvestable ears.

The role of fungi in grain-quality deterioration is well documented (29). The research effort by phytopathologist in this area, however, has been relatively small compared to the magnitude of loss (6). Fungicides offer a possibility for an additional method of control that could be integrated into currently used grain-management techniques. The use of fungicides could dramatically change grain management by allowing for higher moisture at harvest, lower recommended airflow (less energy), or increased probability of successful low-temperature drying. It is important, however, to consider the fact that the fungicides function as protectants. In most years, corn grain at harvest has low levels of infection by storage fungi (27, 34). The application of fungicides immediately after harvest would only affect penetration and infection. Once fungi are established in the kernel, the fungicides would be ineffective. None of the fungicides tested in our studies provided complete control of storage fungi. It is likely that control could be greatly improved by better distribution of fungicides onto kernels. This could be achieved through improved application techniques and/or fungicide formulations.

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