Efficacy of Iprodione for Control of Storage Fungi in Corn

J. TOMAN, JR., Postdoctoral Research Associate, and D. G. WHITE, Associate Professor, Department of Plant Pathology, University of Illinois, Urbana 61801

ABSTRACT

Toman, J., Jr., and White, D. G. 1994. Efficacy of iprodione for control of storage fungi in corn. Plant Dis. 78:27-33.

Three experiments were done to determine the efficacy of the fungicide iprodione (Rovral 50WP, Rhone-Poulenc Ag Company) for control of storage fungi. In 1986, corn (B73 × LH38) harvested at an average of 20.8% moisture was treated with 0, 5, 10, and 20 μg/g (a.i. fungicide/grain weight adjusted to 15% grain moisture); and the experiment was repeated in 1987 at an average harvest moisture of 19.9%. In 1987, an additional experiment was done with corn (Pioneer 3377) harvested at an average moisture of 25.6% and treated with iprodione at 0, 10, 20, and 40 μg/g (a.i. fungicide/grain weight adjusted to 15% moisture). After treatment, the grain was augered into modified grain bins and dried using ambient air. The incidence of storage fungi was determined following plating of kernels on malt salt agar. Fungicide treatments reduced the incidence of *Penicillium* spp. and *Aspergillus* spp. when compared to the untreated control. The control of storage fungi resulted in fewer damaged kernels, as determined by a licensed federal grain inspector. Results suggest that low rates of a fungicide applied at harvest can be integrated with currently used control techniques, thus allowing for maintenance of quality grain.

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

Fungi that cause kernel rots of corn (*Zea mays* L.) can be divided into two groups: field fungi and storage fungi. Fungi classified as field fungi require grain moistures above 20% to grow and are usually responsible for causing ear rot diseases prior to harvest. Losses from ear rots are rarely severe in the midwestern United States, except in years when wet conditions prevail after pollination or where drought and/or insect damage occur. Fungi classified as storage fungi usually grow at less than 18% grain moisture. The most important storage fungi are in the genera *Penicillium* and *Aspergillus* (26). They occasionally may be ear rot pathogens; however, they are not normally associated with the corn kernels until after harvest. Storage fungi are associated with plant debris, soil, and other places where moisture is relatively low. Spores of these fungi are often spread during the mechanical combining of the grain crop. The grain becomes coated with additional spores during the drying process as air with spores is passed through the grain. More spores coat the grain during loading and unloading, and during the blending of fines and/or grain (30). After a kernel is infected, the fungus starts to rot the kernel whenever moisture and/or temperature favor growth. At favorable temperatures, *Aspergillus* spp. can grow in kernels with grain moisture as low as 13.1%, with rapid growth above that; and *Penicillium* spp. actively grow above 16% (35). As fungi grow, they produce metabolic heat and moisture, which create conditions ideal for other fungi, thus speeding the decay process. Therefore, deterioration of grain during shipment and storage is caused by fungi; and prevention of deterioration during shipment and storage is a disease control problem. Current control of storage fungi in the Midwest relies on the integration of three major controls: 1) prevention of mechanical damage during harvest and transportation of grain; 2) maintaining moisture below that optimal for fungal growth; and 3) where possible, maintaining low temperatures (30).

Mechanical damage may occur at different times in the handling of grain. The first opportunity occurs during harvest, when corn kernels are removed from the ear. When corn is harvested at a high moisture, or the combine is in poor adjustment, damage is much greater. Additional damage is done as corn is moved during drying and shipment. Kernels with cracks or exposed starch surfaces are much more susceptible to penetration by storage fungi.

The primary control of storage fungi is to dry corn below the moisture at which fungi will grow. The most common practice is high-temperature drying, where corn is harvested at an average of 20–25% moisture and dried with a high temperature to a moisture of 15–16% (33). High-temperature drying has a major advantage, in that it is very rapid and can be done in wet weather. Its major disadvantages are that it requires a relatively large energy input, in the form of propane or natural gas (28), and that stress cracks may occur as corn is rapidly heated and cooled (31). Stress cracks are a problem in corn, because as grain is handled during shipping, kernels with stress cracks break more readily (31). Stress cracks also act as sites for penetration by fungi.

An alternative to high-temperature drying is low-temperature drying, which is a process of slow drying with ambient air or air heated only a few degrees (1.1–5.6 C or 2–10 F) above ambient (2). This procedure is not as widely used due to the inherent potential for spoilage, because the effectiveness of the drying process depends on ambient air conditions. During falls with warm, moist conditions, grain that is undergoing low-temperature drying may remain at high moisture for long periods (8). Additionally, because of the slow drying rates, low-temperature drying is not recommended for high grain moisture that occurs at harvest in some years (2). Two major advantages of low-temperature drying are that it requires less energy (28) and that it results in little or no stress cracking of grain (15). Grain successfully dried using low temperatures does not break as easily during transportation, contains fewer broken kernels, and thus is of higher quality.

Cool temperatures are used to control storage fungi in much of the upper Midwest. During the winter months, cool air blown through the grain lowers the temperature enough to prevent fungal growth. Additionally, proper aeration at all times during storage will reduce or eliminate "hot spots" that result from and favor fungal growth.

Another potential method for the control of storage molds in grain is the use of chemicals. A number of different methods to chemically control storage fungi have been tested. In 1947, Milner et al (16) tested more than 100 compounds for their fungicidal activity on stored wheat. Some compounds slowed the rate of fungal growth, but none of the compounds tested was consistently effective and safe. Propionic acid has been used as a preservative in stored corn (4,9–13,25), sorghum (11,21,25), barley, oats, wheat (11), and forages (9). Propionic acid treatment increases the

Research support provided by the Illinois Agricultural Experiment Station, the Illinois Corn Marketing Board, and Rhone-Poulenc Ag Company.

This publication reports research involving a pesticide. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and federal agencies before they can be recommended.

Accepted for publication 18 August 1993.

allowable time for completing low-temperature drying of corn, thus allowing for a higher harvest moisture (29). Although propionic acid–treated grain may enhance feeding efficiency in cattle (10), it is corrosive to bins and conveying equipment (3), and renders grain unsuitable for direct human consumption (21). Ammonia also has been tested as a grain preservative in corn (5,9,23) and forages (9). While it is an effective control, ammonia treatment results in discolored grain with a residual ammonia odor (5). Formaldehyde (20), sulfur dioxide (7,8), and sorbic acid (6,25) also have been tested as potential grain protectants. All have some degree of effectiveness, but each has particular disadvantages.

Because storage fungi do not usually invade kernels prior to harvest (24,32), fungicides applied at harvest may be useful as grain protectants during ambient air drying and storage of corn grain. Laboratory experiments with barley samples treated with different fungicides suggested that several compounds, particularly benomyl, may be effective as grain protectants (22). Work with corn has shown that several fungicides including benomyl and thiabendazole prevent infection by storage fungi and effectively protect seed germinability (17–19). Soybean oil, with and without thiabendazole, has been shown to reduce infection by storage fungi (14). The fungicide iprodione (Rovral, Rhone-Poulenc Ag Company) also has been shown to reduce the rate of corn grain deterioration as measured by CO_2 production (1,37). Other experiments with benomyl, thiabendazole, and A9248 in grain bins confirm the efficacy of these compounds as potential grain protectants (35,36).

The objective of this research was to determine the efficacy of different rates of iprodione in conjunction with low-temperature drying.

MATERIALS AND METHODS

Experiments were done in modified, commercially available grain bins at the Agronomy–Plant Pathology South Farm, Urbana, IL. Bins are 5.7 m high at the eve and 4.6 m in diameter. Bins have false bottom drying floors that are divided in half. Each half of a bin is equipped with a fan to deliver 0.079 m^3/min/quintal (0.64 ft^3/min/bu [cfm/bu]) of ambient air at 248.8 Pa (1.0 in.) static pressure, which is much lower than recommended for ambient air drying. Each bin is divided into 16 wedge-shaped experimental units (eight under the control of each fan) to accommodate various treatments. Each fan is controlled with a programmed aeration controller that turns fans on when the relative humidity and temperature of ambient air are conducive for drying and/or storage of grain. For the three experiments, grain moisture was first reduced with continuous aeration (3 wk for lower harvest moisture experiments and 4 wk for the high harvest moisture experiment), and then aeration was controlled by the programmed aeration controller set to Storage I mode. The desired moisture was set at 15.5% with an average of 0.5 hr/day fan run time. The fans ran when the relative humidity and temperature of ambient air favored an equilibrium moisture content of 15.5%. The programmed aeration controller will accumulate a backlog of fan run time and turn on fans when the best ambient air conditions exist. Each wedge-shaped experimental unit has sampling ports that allow access to the grain at various grain depths. For individual experiments, eight wedge-shaped experimental units were used. All experiments were done in a randomized complete-block design with four treatments and two replications.

Corn (B73 × LH38) for the 1986–87 experiment was harvested at an average moisture of 20.8% on 5 October. In this experiment, iprodione (Rovral 50WP) was tested at 0, 5, 10, and 20 $\mu g/g$ (a.i. fungicide/grain weight adjusted to 15% grain moisture). In 1987–88, two experiments were done, one which repeated the 1986–87 experiment at an average harvest moisture of 19.9% on 10 September. In the other experiment, rates of 0, 10, 20, and 40 $\mu g/g$ (a.i. fungicide/grain weight adjusted to 15% grain moisture) were tested using corn (Pioneer 3377) harvested on 10 September at 25.6% grain moisture. A different corn hybrid was used in the higher harvest moisture experiment in order to obtain high moisture grain at the time the experiment was begun. Fungicide treatments were applied using a treater auger and metering pump. Approximately 350 ml of water per quintal was used as a carrier for the fungicide, and controls were treated with water.

Grain samples were taken prior to treatment, post-treatment, and at weekly intervals for 40 wk from 1.2 m (bottom level), 2.4 m (middle level), and 3.6 m (top level) above the grain bin drying floor. Samples were evaluated for grain moisture with a Dickey-John GAC II moisture meter. Fifty whole, randomly selected kernels from each sample were surface sterilized in a 1.575% sodium hypochlorite (30% commercial bleach) solution for 1 min and then plated, 10 kernels to a plate, on malt salt agar. After 1 wk at room temperature (approximately 23 C), the number of kernels infected with particular fungal species was recorded. Samples taken every 4 wk were sent to a licensed federal grain inspector (Champaign, IL) for determination of percent damage.

The number of kernels from which *Penicillium* spp. were isolated was converted to percentage. The number of kernels from which different *Aspergillus* spp. (*A. flavus* Link:Fr., *A. glaucus* Link:Fr. group, *A. niger* Teigh., *A. ochraceus* K. Wilh.) were isolated was summed for the total *Aspergillus* spp. The total *Aspergillus* spp. was used to provide for an estimate of control of all *Aspergillus* spp. The area under the curve (AUC) was calculated (27) from data of the percent *Penicillium* spp., total *Aspergillus* spp., percent damage, and grain moisture for each sampling level, and averaged over sampling levels for each replicate. AUC values were also calculated for grain moisture of each treatment at each sampling level and for treatments combined at each level. Analysis of variance was used to detect significant differences for percent *Penicillium* spp., total *Aspergillus* spp., and percent damage for each sampling level and for the average of the three sampling levels, and for average grain moisture of all treatments at each sampling level (SAS Institute, Cary, NC).

RESULTS

1986 And 1987 lower harvest moisture experiments. AUC values for grain moisture of the various treatments were not significantly different from each other at any sampling level or combined over levels (AUC values not shown). AUC values calculated for the average of all treatments at individual sampling levels were significantly different among sampling levels in both lower harvest moisture experiments. Grain at the bottom sampling levels dried more rapidly and maintained a lower grain moisture than grain from the middle or top sampling levels (Fig. 1).

In the 1986 experiment, all rates of iprodione reduced the incidence of *Penicillium* spp. compared to the control (Fig. 1). The AUC values of corn grain treated with the three rates of fungicide were significantly different than the control but not significantly different from each other at the bottom or top sampling level. The AUC value of corn grain treated with the 20 $\mu g/g$ rate was significantly lower than the AUC value of the other rates at the middle sampling level and averaged over all sampling levels (Table 1). The percent kernels from which *Penicillium* spp. were isolated increased rapidly to an average of 40.7% over all levels in the control by week 1. At the end of the experiment, the incidence of *Penicillium* spp. in the control averaged 53% over all sampling levels, whereas *Penicillium* spp. isolated from fungicide-treated corn grain averaged 20.7% or below over all sampling levels throughout the 40 wk. In the 1987 experiment, the incidence of *Penicillium* spp. in the control increased at a slower rate to an average of 46% at week 4. An increase in the fungicide rate decreased the AUC value of percent *Penicillium* spp. at each sampling level and averaged over all levels, although the differences between the fungicide rates were not significantly different except at the top sampling level (Table 1).

Iprodione also provided effective control of *Aspergillus* spp. (Fig. 1). In the 1986 experiment, total *Aspergillus* spp. AUC values for the various rates of iprodione were significantly different from the control at all levels and averaged over levels (Table 1). Total *Aspergillus* spp. isolated from the control averaged 16.5 over all sampling levels at week 3 with the following frequencies: *A. glaucus* (18.2%), *A. flavus* (40.4%), *A. niger* (40.4%), and *A. ochraceus* (1%). At week 40, the total *Aspergillus* spp. isolated from the control averaged 36.3 with the following frequencies: *A. glaucus* (63.6%), *A. flavus* (13.1%), and *A. niger* (23.3%). Averaged over all sampling levels, corn grain treated with 5, 10, and 20 μg/g rates had 4.8, 2.8, and 1.2 total *Aspergillus* spp., respectively, at week 3 and increased to 12.3, 11.8, and 9.5, respectively, by week 40. The frequency of isolation of the various *Aspergillus* spp. in the treated corn grain was similar to the control. There were significant differences among AUC values of different fungicide rates at the bottom and middle sampling levels, but

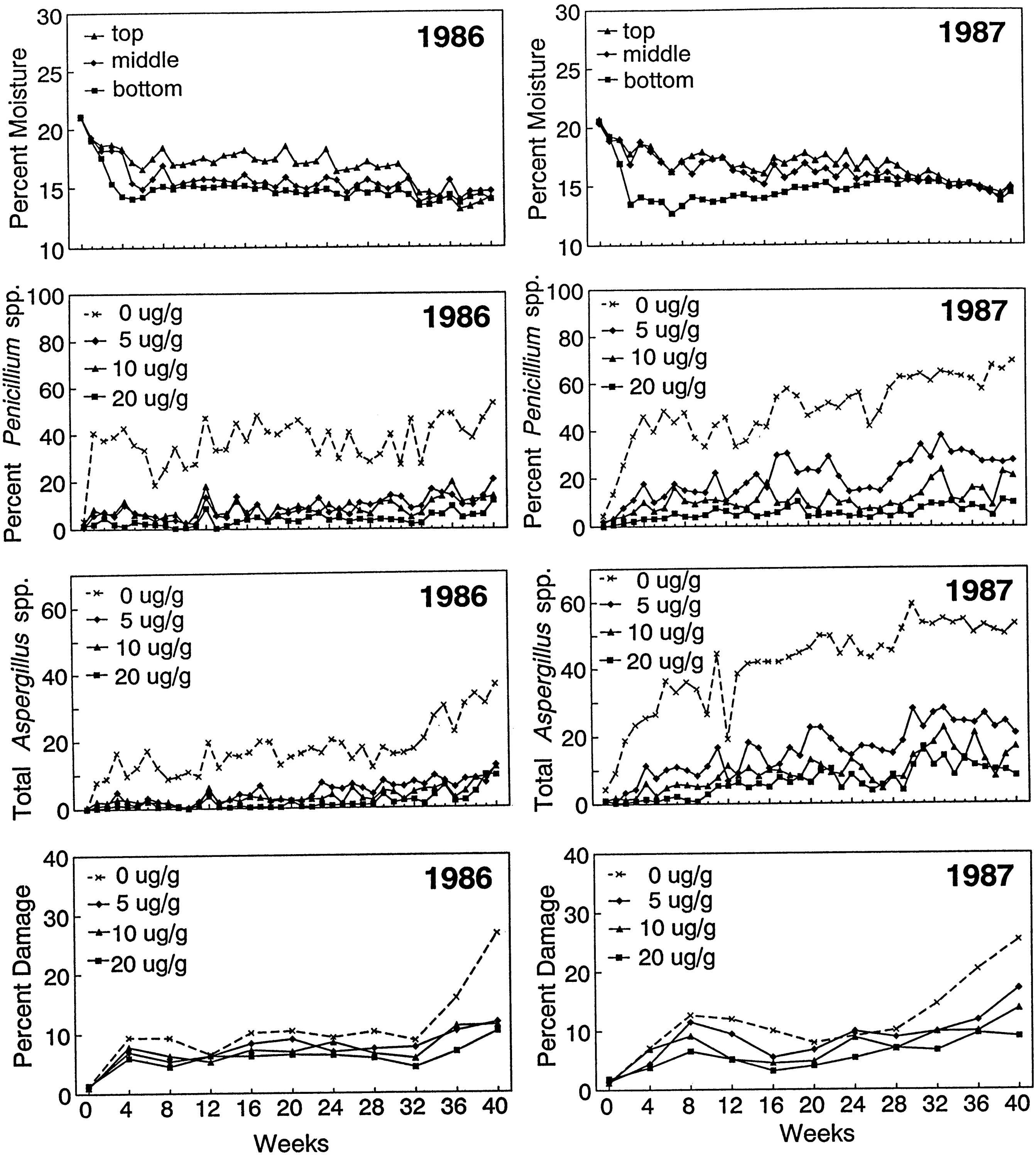

Fig. 1. Effect of fungicide application on corn grain with lower harvest moisture in 1986 and 1987. Percent moisture in corn grain from three bin sampling levels averaged over two replicates and all treatments. Percent kernels (n = 50) from which *Penicillium* spp. and total *Aspergillus* spp. (sum of the number of kernels [n = 50] for different *Aspergillus* spp.) were isolated averaged over two replicates and three bin sampling levels. Percent damage as determined by a licensed federal grain inspector averaged over two replicates and three bin sampling levels. Sampling levels, bottom, middle, and top, were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively.

not averaged over levels, or at the top sampling level (Table 1). In the 1987 experiment, the incidence of *Aspergillus* spp. was lower than in the 1986 experiments. All rates of the fungicide reduced infection when compared to the control (Fig. 1). Total *Aspergillus* spp. isolated from the control averaged 23.3 over all levels at week 3 with the following frequencies: *A. glaucus* (95.7%), *A. niger* (2.9%), and *A. ochraceus* (1.4%). The highest incidence of *Aspergillus* spp. in the control occurred at week 30 with the following frequencies: *A. glaucus* (76.1%), *A. flavus* (8.5%), *A. niger* (13.5%), and *A. ochraceus* (1.9%). There were fewer isolations of *Aspergillus* spp. from treated corn grain with frequencies of the various species being similar to the control. At week 3, total *Aspergillus* spp. averaged over all levels were only 4.3, 1.7, and less than 1 for the 5, 10, and 20 μg/g rates, respectively. For the duration of the experiment, total *Aspergillus* spp. in the treated corn grain was less than in the untreated control.

Percent damage of untreated corn grain was greater than for fungicide-treated grain (Fig. 1). At increased fungicide rates, there was a reduction in the percent damage AUC value. In the 1986 experiment, percent damage AUC values of treated corn grain were significantly different than the AUC values of the control at the middle sampling level and averaged over all levels (Table 1). In 1986, damage of the control treatment at week 4 averaged over all levels was 9.4% and varied between 6.5 and 26.6% for the duration of the experiment. Corn grain treated with 5 μg/g iprodione had 6.9% damage averaged over all levels at week 4 and varied between 5.4 and 11.8% for the duration of the experiment. Damage at the 10 and 20 μg/g rates were 7.8 and 5.9%, respectively, at week 4. Damage fluctuated between 5.3 and 11.3% for the 10 μg/g rate, and between 4.3 and 10.3% for the 20 μg/g rate for the remainder of the 40 wk experiment. In 1987, damage of the control treatment at week 4 averaged over all levels was 7.1% and varied between 7.9 and 25.2% for the duration of the experiment. Damage of corn grain treated with the 5 μg/g rate averaged over all levels was 4.4% at week 4, and varied between 5.5 and 17.1% through week 40. Damage of corn grain treated at the 10- and 20-μg/g rates averaged over all levels was 6.9 and 3.7%, respectively, at week 4 and varied between 4.5 and 13.7% and between 3.2 and 9.6% for the 10- and 20-μg/g rates, respectively, for the duration of the experiment.

1987 High moisture experiment. AUC values for grain moisture of the various treatments were not significantly different from each other at any sampling level or combined over levels (AUC values not shown). When AUC values were calculated for the average of all treatments at individual sampling levels, there were significant differences between moisture at each of the three levels. As in the lower harvest moisture experiments, corn grain at the bottom sampling level dried more rapidly and maintained lower moisture (Fig. 2). Grain at the bottom sampling level was reduced to an average of 12.1% at week 4. Grain moisture slowly increased to an average of 13.9% by week 13 and was maintained at approximately 14% for the duration of the experiment. At the middle sampling level, grain moisture was an average of 20.1% at week 4 and was maintained at an average moisture between 14.6 and 20.1%. At the top level, grain moisture was 19.8% at week 4 and was maintained at an average of 14.3 to 25.1% for the duration of the experiment.

The AUC values for percent *Penicillium* spp. for all fungicide treatments were significantly different from the control at each sampling level and averaged over all sampling levels (Table 1). At the bottom sampling level, percent *Penicillium* spp. AUC values for corn grain treated with the different fungicide rates were not significantly different from each other. At the middle and averaged over all levels the percent *Penicillium* spp. AUC values for corn grain treated with the 20 and 40 μg/g rates were significantly lower than the AUC value of corn grain treated with the 10 μg/g rate. At the top level, all AUC values of percent *Penicillium* spp. were significantly different from each other, with the higher fungicide rates having the lower values. The incidence of *Penicillium* spp. in the control treatment was greater than in the other treatments throughout the exper-

Table 1. The area under disease progress curve (AUC)[a] for incidence of *Penicillium* and *Aspergillus* spp., and percent damage of corn grain treated with various rates of iprodione

Year Rate (μg/g)	*Penicillium* spp.[b]				*Aspergillus* spp.[c]				Damaged (%)[d]			
	B[e]	M[f]	T[g]	A[h]	B	M	T	A	B	M	T	A
1986 (Harvest moisture 20.8%)												
0	1,351	1,568	1,542	1,487	605	726	722	684	360	390	502	417
5	266	349	475	345	162	150	231	181	228	280	395	301
10	221	295	474	348	86	126	198	136	266	260	339	289
20	79	149	218	149	27	49	131	69	207	215	285	236
LSD (5%)[i]	197	97	554	181	111	68	353	161	ns	69	ns	101
1987 (Harvest moisture 19.9%)												
0	1,589	2,032	2,282	1,968	1,621	1,700	1,657	1,659	321	461	625	469
5	539	875	1,062	826	374	714	820	636	212	334	502	350
10	279	424	615	440	201	375	568	381	175	284	415	291
20	148	234	275	219	80	3[illegible]	380	256	166	224	290	227
LSD (5%)	661	721	695	682	252	378	585	318	ns	ns	ns	ns
1987 (Harvest moisture 25.6%)												
0	1,626	2,074	2,260	1,987	296	481	786	521	731	1,063	1,219	1,004
5	454	732	895	694	73	113	193	126	556	810	922	762
10	218	395	506	373	24	59	125	69	551	789	967	769
20	146	188	259	198	22	32	79	44	429	623	647	566
LSD (5%)	485	322	99	286	28	99	181	92	ns	230	115	183

[a] AUC = $E[(Y_{i+1} + Y_i)/2]\,[X_{i+1} - X_i]$, Y_i = the number of infected kernels at the ith observation, X_i = weeks of the ith observation, n = total number of observations, i = the week of rating.
[b] % *Penicillium* spp. is based on the 50 kernels evaluated in each of the two replicates.
[c] *Aspergillus* spp. is the sum of *Aspergillus* spp. (*A. flavus, A. glaucus, A. niger,* and *A. ochraceus*) from 50 kernels in each of two replicates.
[d] As determined by a licensed federal grain inspector.
[e] AUC at the bottom sampling level, 1.2 m from the drying floor.
[f] AUC at the middle sampling level, 2.4 m from the drying floor.
[g] AUC at the top sampling level, 3.6 m from the drying floor.
[h] AUC averaged over all three sampling levels, bottom, middle, and top.
[i] Waller Duncan Bayesian LSD test (*k*-ratio = 100).

iment (Fig. 2). Averaged over all levels, the percent kernels in the control from which *Penicillium* spp. were isolated increased rapidly until week 4 with an average of 54.7% and varied between 34 and 74% for the duration of the experiment. Corn grain treated at the 10-μg/g rate averaged 23.3% *Penicillium* spp. at week 4 and varied between 37.3 and 50.3% for the duration of the experiment. Corn grain treated with the 20- and 40-μg/g rates averaged 11.3 and 2.7% *Penicillium* spp., respectively, at week 4. For the duration of the experiment, the *Penicillium* spp. averaged 5.3–25.0% and 1.7–15.7% for corn grain treated with the 20- and 40-μg/g rates, respectively.

The incidence of *Aspergillus* spp. was not as great in the high harvest moisture experiment as in the lower harvest moisture experiments (Fig. 2). The AUC values of total *Aspergillus* spp. for all fungicide treatments were significantly lower than the control at each level and averaged over all levels (Table 1). At the bottom sampling level, there was also a significant difference between the AUC values of the fungicide rates. Significant differences did not occur at the middle, top, and averaged over all levels. As in the other experiments, *Aspergillus* spp. were isolated more frequently from kernels from the upper sampling levels. The most frequently isolated *Aspergillus* sp. throughout the experiment was *A. glaucus*.

Percent damage was greater for the untreated than for the fungicide-treated corn grain (Fig. 2). AUC values of percent damage were generally less with higher fungicide rates. At the top and averaged over all levels, the AUC value of the 40-μg/g rate was significantly less than for other treatments. There was an increase in the amount of damage at each successive (bottom, middle, and top) sampling level. Damage was greater in the high harvest moisture experiment than in the lower harvest moisture experiments (Table 1). Damage of corn grain from the control at week 4 averaged over all sampling levels was 20.3% and varied between 19.4 and 35.1% for the duration of the experiment. Corn grain treated with 10 μg/g of iprodione had 14% damage at week 4 and varied between 16.2 and 29.2% for the duration of the experiment. Damage at the 20- and 40-μg/g rates were 15.3 and 11.3%, respectively, at week 4. Damage varied between 16.8 and 26.9% for the 20-μg/g rate, and between 9.1 and 22.5% for the 40-μg/g rate for the duration of the experiment.

DISCUSSION

Repeating a grain storage experiment, while maintaining control of all variables, is not possible due to environmental conditions leading up to and following harvest. 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 kernels, influence the incidence and severity of damage caused by storage fungi (30). Overall, there were similar results in all three experiments, even though the magnitude of control and fungicide rate differences were not necessarily consistent between experiments. The fungicide iprodione significantly reduced the incidence of *Penicil-*

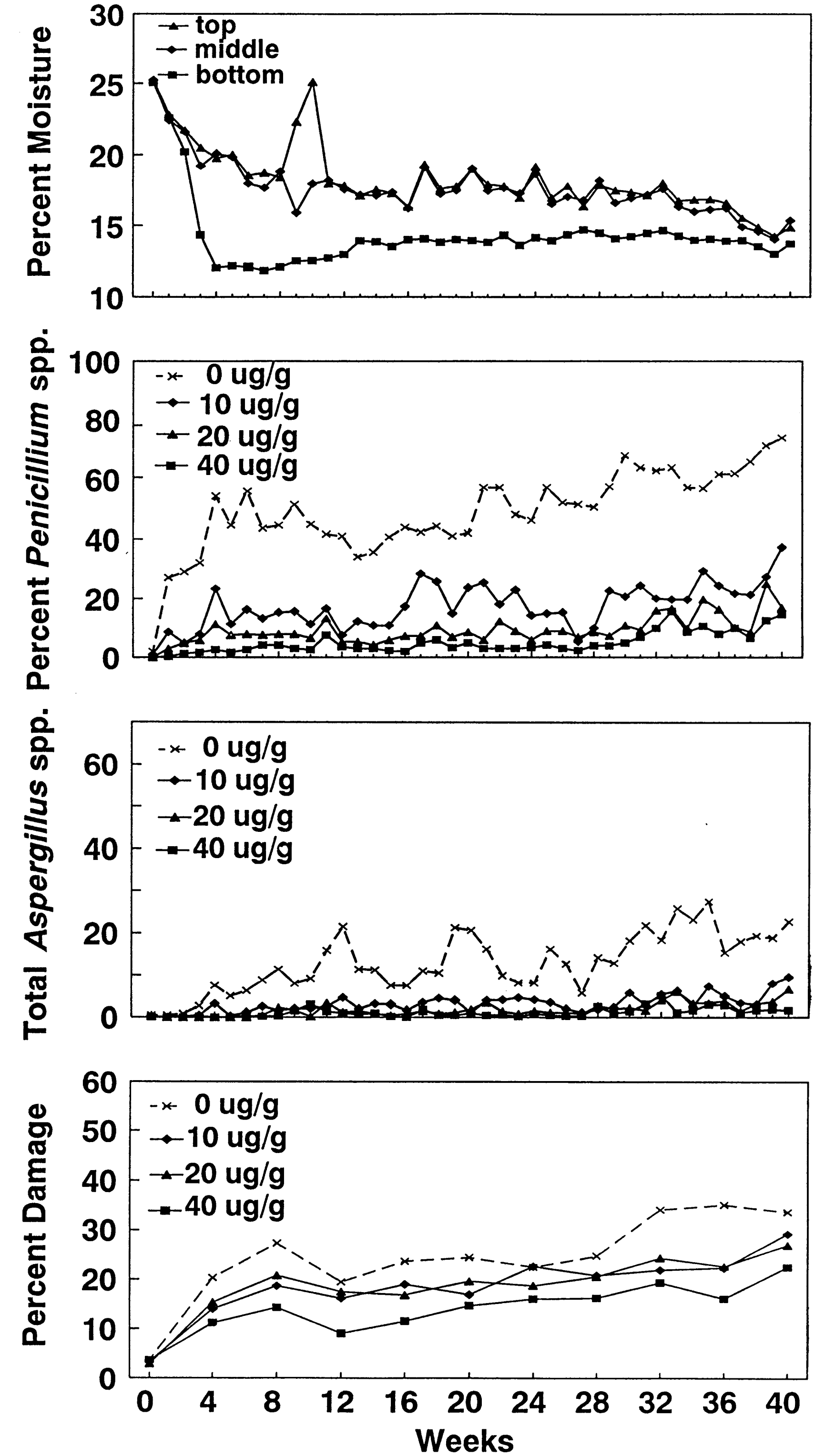

Fig. 2. Effect of fungicide application on corn grain with high harvest moisture in 1987. Percent moisture of corn grain from three bin sampling levels averaged over two replicates and all treatments. Percent kernels (n = 50) from which *Penicillium* spp. and total *Aspergillus* spp. (sum of the number of kernels [n = 50] for different *Aspergillus* spp.) were isolated averaged over two replicates and three bin sampling levels. Percent damage as determined by a licensed federal grain inspector averaged over two replicates and three bin sampling levels. Sampling levels, bottom, middle, and top, were 1.2, 2.4, and 3.6 m above the grain bin drying floor, respectively.

lium and *Aspergillus* spp., which corresponded with a general reduction in percent damage. We attributed the higher frequency of *Penicillium* and *Aspergillus* spp. in the 1987 lower harvest moisture experiments compared to the 1986 experiment to the different environmental conditions (temperature, relative humidity) at and following harvest. In 1987, harvest was on 10 September and the grain was maintained at warmer temperatures and higher moisture for a longer time than in 1986, when the harvest date was 5 October. In the 1987 experiment, the incidence of *Aspergillus* spp. was more than twice that of the 1986 lower harvest moisture experiment. Most differences were due to a rapid increase in *Aspergillus* spp. early in the experiment that did not occur in 1986. The greater frequency of *A. flavus* early in the 1986 experiment was likely the result of the drier summer and conducive moisture (15–16%) of the grain mass early in the experiment. The 1987 higher harvest moisture experiment provides insight as to the extent a fungicide will effectively control storage fungi at much higher than recommended harvest moisture.

In all three experiments, the use of iprodione resulted in significantly lower incidence of *Aspergillus* and *Penicillium* spp. than in the control. These differences, however, did not always correspond to significant differences in percent damage as determined by a licensed federal grain inspector, although there was generally a reduction in AUC values for percent damage with increased fungicide rates. The lack of significant differences in AUC values of percent damage between treated and untreated may be partially due to factors other than lack of control by the fungicide. Percent damage was determined every 4 wk, whereas incidence of *Aspergillus* and *Penicillium* spp. was determined weekly. Additionally, the magnitude of difference of percent *Penicillium* spp. and total *Aspergillus* spp. between treatments was much greater than the damage, and those smaller differences may not be detectable with only two replicates. More frequent sampling and increased replicates may have allowed for more precise detection of significant differences; however this was not done due to cost. Other problems exist with the methods used to determine damage. When determining damage, a 250-g sample is first cleaned by screening over a 4.76-mm (12/64 inch) round-hole screen. Kernels are then classified as sound or mold-damaged on the basis of their appearance. A kernel of corn is considered damaged for inspection and grading purposes, as defined in the Grain Inspection Handbook, "only when the damage is distinctly apparent and of such character as to be recognized as damaged for commercial purposes" (34). The determination of percent damage is therefore subjective. Estimation of percent damage is compounded by the random assignment of samples to several different grain inspectors. The lack of consistency between individual inspectors has been identified as a problem in other research (37). In addition to the subjectiveness of determination of percent damage, the use of AUC values to summarize all data may mask treatment differences at particular times during the experiment. For example, AUC values of fungicide treatments for damage in the 1987 lower harvest moisture experiment were not significantly different from the control. Until week 36, the differences in percent damage between treatments were small and not significant. When AUC values were calculated averaged over all levels for weeks 36–40, the fungicide treatments were significantly different from the control. AUC values allow all data to contribute in the analysis and are a realistic approach for summarizing grain storage data over entire experiments.

One major disadvantage of low-temperature drying is the currently recommended grain harvest moisture (2). Farmers would rather not allow grain to dry in the field because stalk rot and subsequent stalk lodging result in nonharvestable ears. Grain harvest moisture recommendations are based on the average relative humidities and temperature of air at different times in the fall. The recommended harvest moisture is lower in the fall (September) because the warmer temperature favors fungal growth. The recommended harvest moisture is also lower by mid-November because the drying potential of the air (cool and wet) is usually less. Recommendations are established to allow for successful drying without excessive damage (greater than 5% damage) by fungi in only 9 out of 10 years. The recommended harvest moisture of 5 October would be 20.5% (1986 experiment) and on 10 September would be 20.0% (1987 experiments) at an airflow of 0.154 m^3/min/quintal (1.25 cfm/bu) (2). Harvest moistures in our lower harvest moisture experiments were 20.8% on 5 October and 19.9% on 10 September and 25.6% in the high harvest moisture experiment; however, the airflow rate in the experimental bins was only 0.79 m^3/min/quintal (0.64 cfm/bu). The high harvest moisture experiment of 1987 exceeded the harvest moisture recommendation based on a 0.154 m^3/min/quintal airflow rate by 5.6%. Differences in airflow and harvest moisture are very important. For example, on 1 October the recommended airflow would be 0.123 m^3/min/quintal (1.0 cfm) for corn harvested at 20% grain moisture and 0.247 m^3/min/quintal (2.0 cfm) for corn harvested at 22% grain moisture. A 2% increase in grain harvest moisture would result in a doubling of the recommended airflow. In general, the airflow in the experimental bins is half of the recommended cubic meters per minute for the harvest moisture used in the lower harvest moisture experiments. Recommendations for maintaining grain quality would also suggest that the grain should be dried to 15–16% moisture as quickly as possible in the fall and to 14% moisture for storage through the spring and summer. The objective of our experiments was to determine the efficacy of fungicides and not necessarily to maintain commercially acceptable grain quality (less than 5% damage). In order to accomplish this goal, we designed the experimental bins with relatively low airflow. Damage of the control treatment exceeded 5% by week 4 in all three experiments. Damage of grain treated with 20 μg/g iprodione in the two lower harvest moisture experiments ranged from an average of 4.3 to 10.3% in 1986 and 3.2 to 9.6% in 1987.

The use of a fungicide as a grain protectant offers an additional method of control that can be integrated into currently used grain management techniques, suggesting that fungicides can allow for higher moisture at harvest, less energy (fewer cubic meters per minute), or increased probability of successful low-temperature drying. It is extremely important, however, to consider that the fungicide functions as a protectant. Corn grain at harvest has very low levels of infection by storage fungi in most years (24,32). The immediate application of fungicides after harvest would only affect penetration and infection. Fungicides would be ineffective once fungi are established in the kernel. The use of iprodione alone, without good grain-management practices, will not provide satisfactory control of storage fungi. More emphasis should be placed on improved formulations and treating technology to increase efficacy.

LITERATURE CITED

1. Al-Yahya, S. A., Bern, C. J., Misra, M. K., and Bailey, T. B. 1991. Carbon-dioxide evolution of fungicide-treated high-moisture corn. Am. Soc. Agric. Eng. Pap. 91-6557.
2. Anonymous. 1980. Low Temperature and Solar Grain Drying Handbook. Midwest Plan Service, Iowa State University, Ames.
3. Bartsch, J. A., Finner, M. F. 1976. A low temperature grain drying experiment in an artificially reproduced environment. Trans. ASAE 19:378-381.
4. Bothast, R. J., Adams, G. H., Hatfield, E. E., and Lancaster, E. B. 1975. Preservation of high-moisture corn: a microbiological evaluation. J. Dairy Sci. 58:386-391.
5. Bothast, R. J., Lancaster, E. B., and Hesseltine, C. W. 1972. Ammonia kills spoilage molds in corn. J. Dairy Sci. 56:241-245.
6. Dunkel, F., Lung, P. Z., Chuan, L., and Yin, H. F. 1982. Insect and fungal response to sorbic acid-treated wheat during storage in south China. J. Econ. Entomol. 75:1083-1088.
7. Eckhoff, S. R., Tuite, J. F., Foster, G. H., Kirleis, A. W., and Okos, M. R. 1983. Microbial growth inhibition by SO_2 or SO_2 plus NH_3 treatments during slow drying of corn. Cereal Chem. 60:185-188.
8. Eckhoff, S. R., van Cauwenberge, J. E., Bothast, R. J., Nofsinger, G. W., and Bagley, E. B. 1980.

Sulfur dioxide-supplemented ambient air drying of high-moisture corn. Trans. ASAE 23:1028-1032.
9. Goering, H. K., and Gordon, C. H. 1973. Chemical aids to preservation of high moisture feeds. J. Dairy Sci. 56:1347-1351.
10. Hall, G. E., Hill, L. D., Hatfield, E. E., and Jensen, A. H. 1974. Propionic-acetic acid for high-moisture corn preservation. Trans. ASAE 17:379-382.
11. Herting, D. G., and Drury, E. E. 1974. Antifungal activity of volatile fatty acids on grains. Cereal Chem. 51:74-83.
12. Jones, G. M., Donefer, E., and Elliot, J. I. 1970. Feeding value for dairy cattle and pigs of high moisture corn preserved with propionic acid. Can. J. Anim. Sci. 50:483-489.
13. Larsen, H. J., Jorgensen, N. A., Barrington, G. P., and Niedermeier, R. P. 1971. Effect of organic acids on preservation and acceptability of high moisture corn. (Abstr.) J. Dairy Sci. 55:685.
14. McGee, D. C., Iles, A., and Misra, M. K. 1989. Suppression of storage fungi in grain with soybean oil. (Abstr.) Phytopathology 79:1140.
15. Mensha, J. K., Herum, F. L., Blaisdell, J. L., and Stevens, K. K. 1981. Effect of drying conditions on impact shear resistance of selected corn varieties. Trans. ASAE 24:1568-1572.
16. Milner, M., Christensen, C. M., and Geddes, W. F. 1947. Grain storage studies. VII. Influence of certain mold inhibitors on respiration of moist wheat. Cereal Chem. 24:507-517.
17. Moreno-Martinez, E., Mandugano, L., Mendoza, M., and Valencia, G. 1985. Use of fungicides for corn seed viability preservation. Seed Sci. Technol. 13:235-241.
18. Moreno-Martinez, E., and Ramirez, J. 1985. Protective effect of fungicides on corn seed stored with low and high-moisture contents. Seed Sci. Technol. 13:285-290.
19. Moreno-Martinez, E., and Vidal-Gaona, G. 1981. Preserving the viability of stored maize seed with fungicides. Plant Dis. 65:260-261.
20. Muir, W. E., and Wallace, H.A.H. 1972. Effects of treating damp grain with formaldehyde to prevent storage deterioration. Can. J. Plant Sci. 52:375-379.
21. Nelson, L. R., Cummins, D. G., Harris, H. B., and Baird, D. M. 1973. Storage of high moisture sorghum [*Sorghum bicolor* (L.) Moench] treated with propionic acid. Agron. J. 65:423-425.
22. Niles, E. V. 1980. Fungi in stored barley treated with systemic fungicides. Pestic. Sci. 11:458-466.
23. Nofsinger, G. W., Bothast, R. J., and Anderson, R. A. 1979. Field trials using extenders for ambient-conditioning high-moisture corn. Trans. ASAE 22:1208-1213.
24. Qasem, S. A., and Christensen, C. M. 1958. Influence of moisture content, temperature, and time on the deterioration of stored corn by fungi. Phytopathology 48:544-549.
25. Sauer, D. B., and Burroughs, R. 1974. Efficacy of various chemicals as grain mold inhibitors. Trans. ASAE 17:557-559.
26. Sauer, D. B., Meronuck, R. A., and Christensen, C. M. 1992. Microflora. Pages 313-340 in: Storage of Cereal Grains and Their Products. 4th ed. D. B. Sauer, ed. American Association of Cereal Chemists, St. Paul, MN.
27. Shaner, G., and Finney, R. E. 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67:1051-1056.
28. Shove, G. C. 1970. Potential energy use in low-temperature grain conditioning. Trans. ASAE 13:58-60.
29. Shove, G. C., and Walter, M. F. 1974. Grain preservative extends allowable drying time. Am. Soc. Agric. Eng. Pap. 74-3533.
30. Smith, D. R., and White, D. G. 1988. Diseases of Corn. Pages 687-766 in: Corn and Corn Improvement. 3rd. ed. G. F. Sprague and D. W. Dudley, eds. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.
31. Thompson, R. A., and Foster, G. H. 1963. Stress cracks and breakage in artificially dried corn. U.S. Dep. Agric. Mark. Res. Rep. 631.
32. Tuite, J. 1961. Fungi isolated from unstored corn seed in Indiana in 1956-1958. Plant Dis. Rep. 45:212-215.
33. Tuite, J., and Foster, G. H. 1979. Control of storage diseases of grain. Annu. Rev. Phytopathol. 17:343-366.
34. U.S. Department of Agriculture, Federal Grain Inspection Service. 1988. Corn. Pages C-1 to C-4 in: U.S. Dep. Agric. Grain Inspection Handbook II.
35. White, D. G., Shove, G. C., and Peterson, W. H. 1988. Fungicides reduce corn drying and storage risks. Am. Soc. Agric. Eng. Pap. 88-6075.
36. White, D. G., Toman, J., Burnette, D. C., and Jacobsen, B. J. 1993. The effect of postharvest fungicide application on storage fungi of corn during ambient air drying and storage. Plant Dis. 77:562-568.
37. Wilcke, W. F., Meronuck, R. A., Morey, R. V., Ng, H. F., Lang, J. P., and Jiang, D. 1992. Deterioration rates of shelled corn treated with mold inhibitors. Am. Soc. Agric. Eng. Pap. 92-6044.