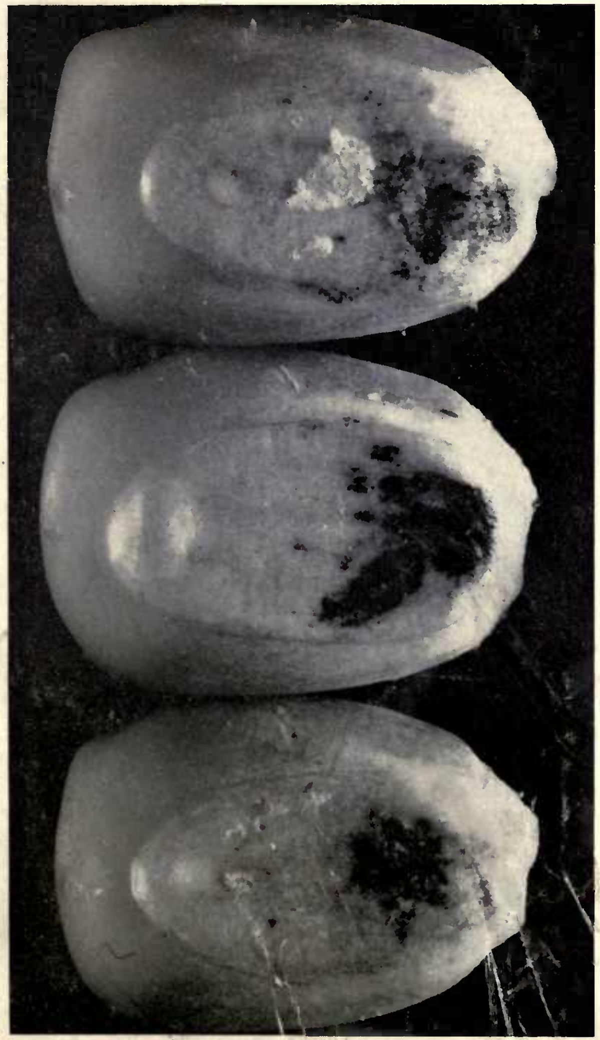
CORN
EAR ROTS IN ILLINOIS



By BENJAMIN KOEHLER

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CORN EAR ROTS IN ILLINOIS

By Benjamin Koehler, Professor of Plant Pathology

CORN EAR ROT DISEASES continue to be of importance wherever corn is grown. In Illinois, they occur in practically every field and in every season, although they vary greatly in prevalence and amount of damage, not only between years, but from place to place in the same year.

As used in this bulletin, the term "corn ear rot diseases," includes the occurrence of rots and molds in ears or in shelled corn, in the field or in storage. Investigations were limited to ear rots on dent corn, although similar rots may be found on sweet corn, popcorn, and other kinds of corn.

Descriptions of ear rot diseases are given to help the reader identify them and understand their behavior, long-time records of ear rot prevalence are reported, and estimates are made of financial losses. These sections are followed by a discussion of experiments on various factors influencing the prevalence of ear rot, and on methods for artificially inducing ear rots as an aid in selection for resistance. As yet, no commercial hybrids that are highly resistant to the major rot diseases are available, but some are better than others.

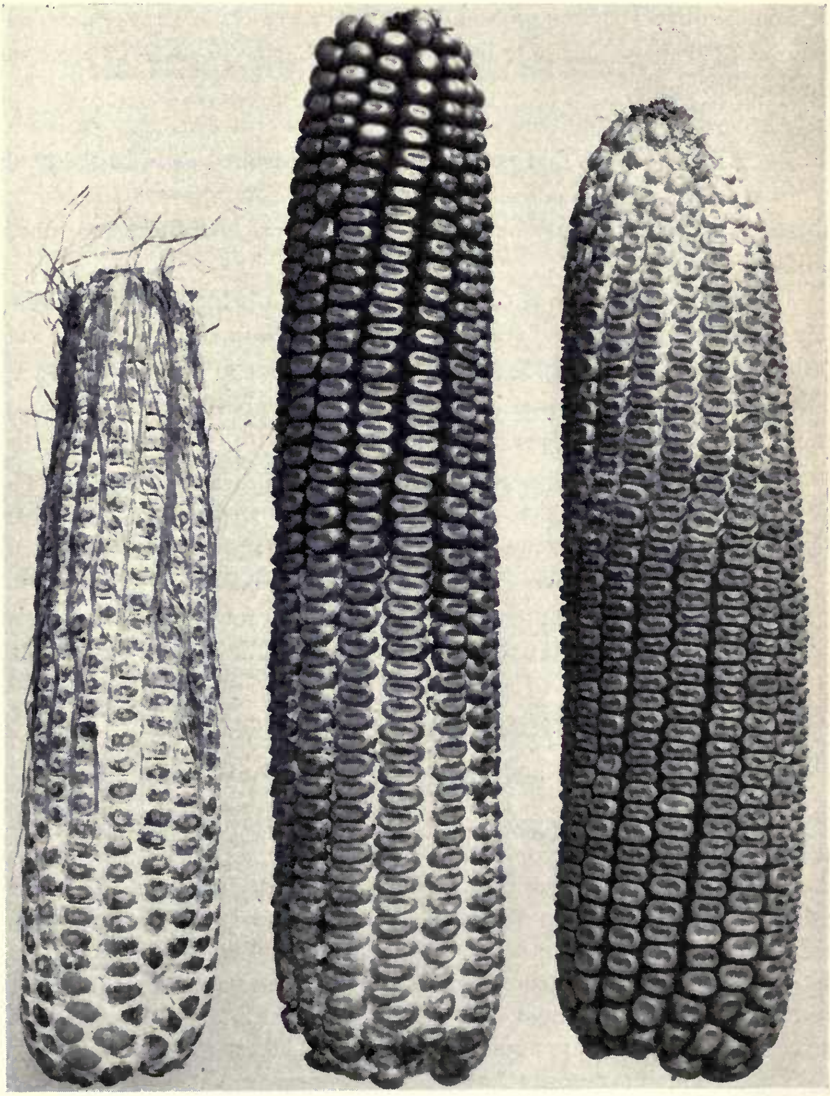
Not all data are shown. Where considerable data were available on a similar subject, only those that were best suited for statistical analysis are presented, but all data are taken into consideration in the discussion.

DESCRIPTIONS OF EAR ROT DISEASES

Diplodia Ear Rot

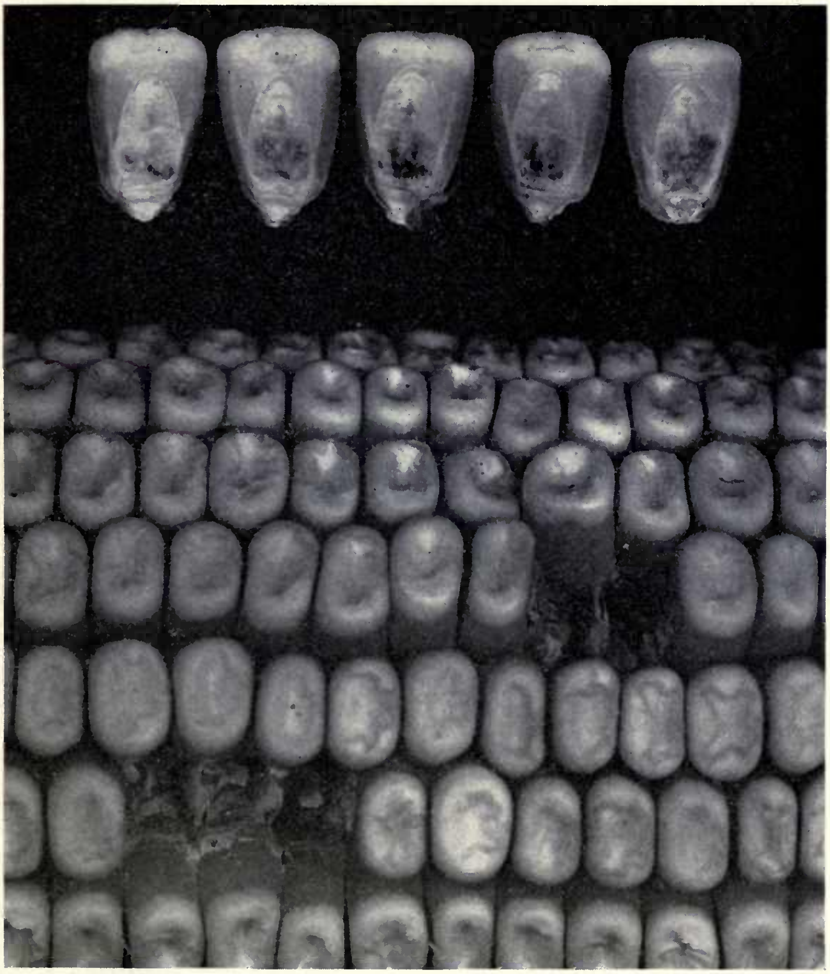
Diplodia zeae (Schw.) Lév. can cause ear infection any time from silking until the ears become too dry. An early infection symptom is that all or part of the husks may prematurely fade from green to straw color. This is sometimes followed by the appearance of a gray area with a dark-purplish rim. When the husks are opened a white mold is seen on the ear. By harvest time early infected ears are completely rotted and light in weight (Fig. 1); the kernels are brownish, the mycelium is a pale gray, and the inner husks adhere tightly to the ear.

The symptoms described above may appear as early as the latter part of August. Most Diplodia ear infections, however, occur a little later, after the ears have made more growth. Although the ear itself is most susceptible in the milk stage, it also has the best husk protection at that time. As the ear grows in length, husk protection at the tip end becomes less and gradually the husks also become looser, making it easier for spores to get to the ear or between the husks. These later



Lightweight mummified ear at left resulted from an early Diplodia infection. The other ears were infected later, rot having started at the butt end of the center ear and at the tip of the righthand ear. (Fig. 1) infections may result either in the complete rotting of the ears, with an abundance of mycelium on the surface, or only a partial rotting (Fig. 1), most frequently of the butt end. In still later infections the mycelium may be barely visible between the rows of kernels; or the ear may appear healthy until after shelling, when it will be seen that the germs have brown discolorations and the kernels are dead (Fig. 2).

Ear infection can advance through the shank from the stalk (Table 9), but more commonly infection becomes active at the base of some husks (Figs. 3, 4) or at an exposed ear tip. As the ear approaches



The Diplodia infection in this ear could not be detected until some of the kernels were removed. (Fig. 2)

Left-hand ear shows Diplodia ear rot that originated on the shank, at the base of some husks that were later removed. Diplodia originated between the husks of the right-hand ear. (Fig. 3)

maturity, the rot progresses more slowly, ceasing completely when the grain has about 21 percent moisture content (24).[a] Ear worms have been found to be of little importance in initiating Diplodia infection (25) (Table 3).

Fruiting bodies (pycnidia) of the fungus may be found on or within completely rotted ears, especially on the inner husks. These pycnidia are black, varying in size but always smaller than, for example, this asterisk: (*). Those within the ear are usually larger than those on the husks and can be easily seen when the ear is broken (Fig. 5). The pycnidia are filled with many microscopic spores, which ooze out

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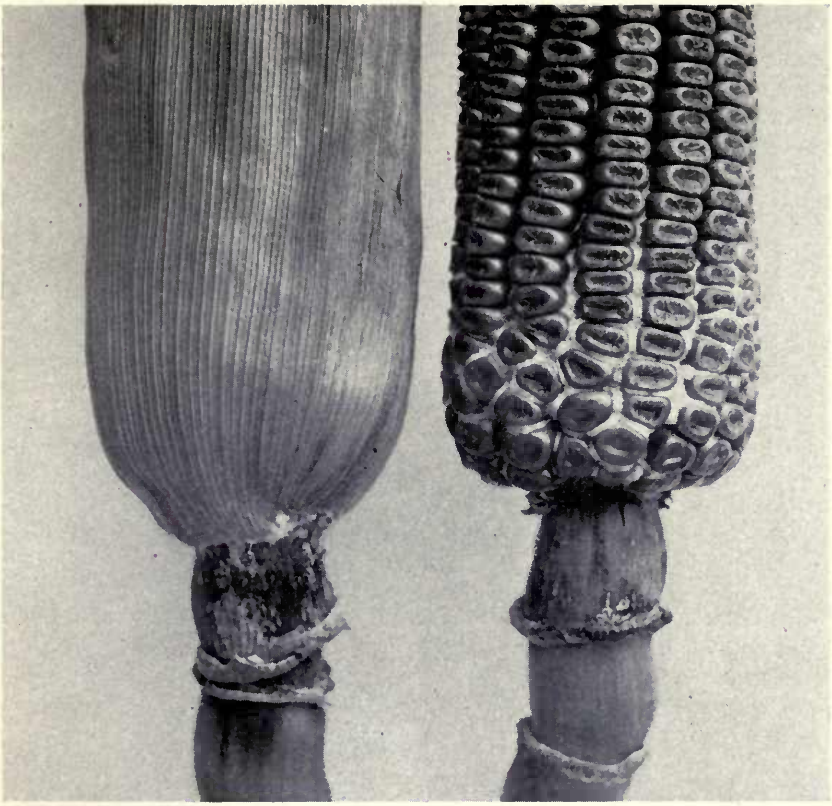
[a] Figures in parentheses refer to literature citations on pages 85 to 87.



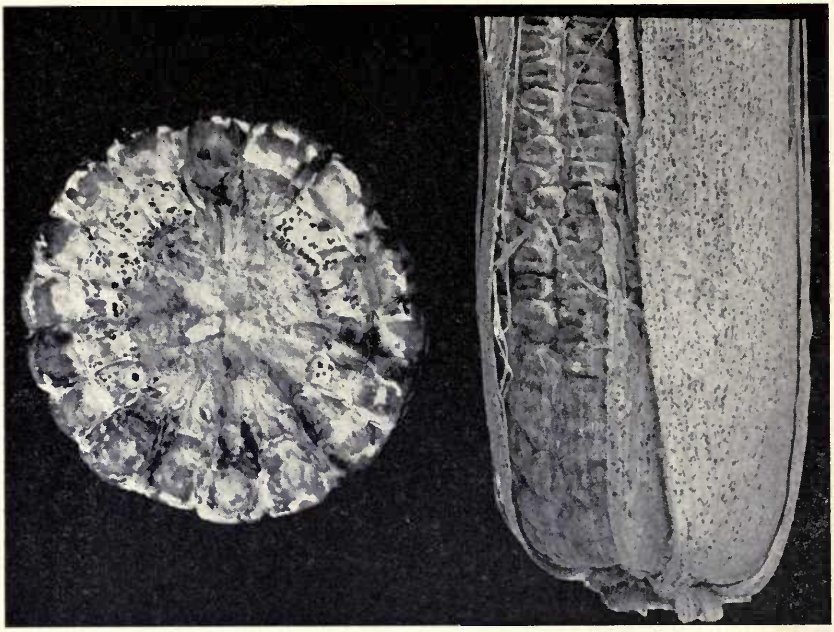
Two ears rotted at the butt end by *Diplodia zeae*. Infection started at the base of the husks of lefthand ear. In the righthand ear, rot resulted from late infection at the tip end (produced in this instance by artificial inoculation 60 days after silking); but the rot developed primarily at the butt, where moisture was highest. (Fig. 4)

under suitable moisture conditions, are carried considerable distances by the wind (3), and thus propagate the disease.

Diplodia zeae attacks the stalks and seedlings of corn plants as well as the ears, but as far as is known, does not attack any other crop.

Diplodia ear rot damage varies greatly from year to year and place to place. The amount of rainfall during August, September, and October is one of the important factors. On the whole, damage has been appreciable in the east-central, eastern, and southern states, but of less importance in Kansas and Nebraska (17, 19).

Diplodia rot not only causes considerable loss in weight of ears, but also decreases the nutritive value (35), and reduces the palatability to



Completely rotted ears showing pycnidia of *Diplodia zeae*. These fruiting bodies contain many microscopic spores. The pycnidia are larger within the broken cross section of the ear than in the husks. (Fig. 5)

pigs (21). When the corn is used for feed, this rot is not as objectionable, however, as that caused by *Fusarium moniliforme* or *Gibberella zeae* (35).

Fusarium Ear Rot

The fungus *Fusarium moniliforme* Sheldon, emend. Snyder and Hansen [*Gibberella fujikuroi* (Saw.) Wr.],[a] appears to be worldwide as a parasite of corn and numerous other crops and is very common in Illinois. On the basis of ears having rot-damaged kernels it is the most prevalent of all ear rots, but when the prevalence is based on

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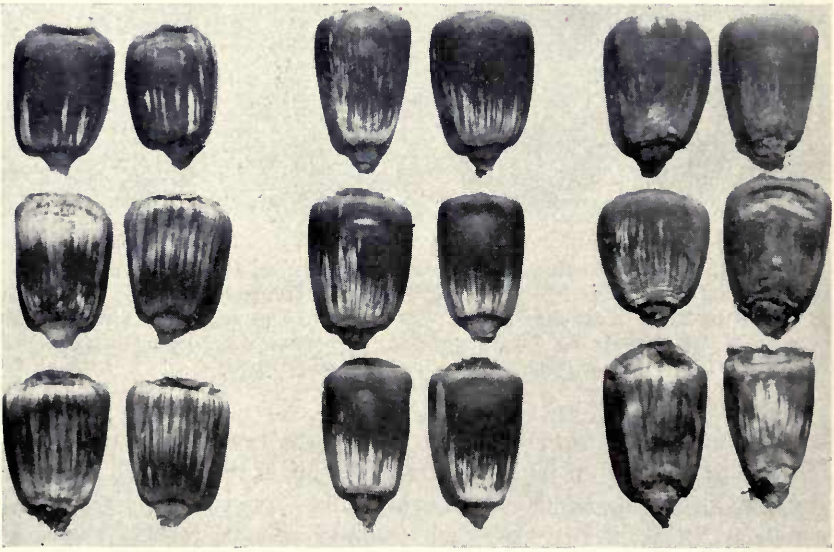
[a] The name *Fusarium moniliforme* is used here rather than *Gibberella fujikuroi* because the Fusarium spore stage is constantly seen in Illinois, while the Gibberella stage has not yet been observed here, although it has been found in some other parts of the United States. No distinction has been made between *F. moniliforme* and *F. moniliforme* var. *subglutinans*. The validity of this distinction is still uncertain. Furthermore, no good criteria exist for distinguishing between these species in routine isolations. A few young colonies on potato dextrose agar medium have borne spores that were primarily catinate, *i.e.* in chains, but by far the most young colonies bore the spores capitate.

Ear rot caused by *Fusarium moniliforme:* (A) rot at tip of ear only, following mechanical damage by ear worms or birds; (B) scattered rot, most of it preceded by growth cracks; (C) rot following ear worm injury more extensive than that on ear A; (D) severe rot, sometimes occurring after husks have been filled with rainwater for a protracted period. (Fig. 6)

kernels in shelled corn discolored by rot, the percentages caused by *F. moniliforme* are on the average slightly lower than those caused by *Diplodia zeae.* The relative importance of ear rots caused by these two pathogens, however, may vary widely and be reversed in different years (Figs. 22, 23) (19). Fusarium rot tends to be less important than Diplodia rot east of Illinois, but this situation is usually reversed south of Illinois and in the Great Plains states (17, 19). Diplodia frequently causes more loss in weight per rotted ear or kernel while Fusarium

Air channels in the pericarp show up as white streaks on these Fusarium-infected kernels. These channels started where the silks had been attached to the crown, but channels may also start where the kernel joins the pedicel. The condition develops when soaking rains come a little later than those causing the condition shown in Fig. 6D. (Fig. 7)

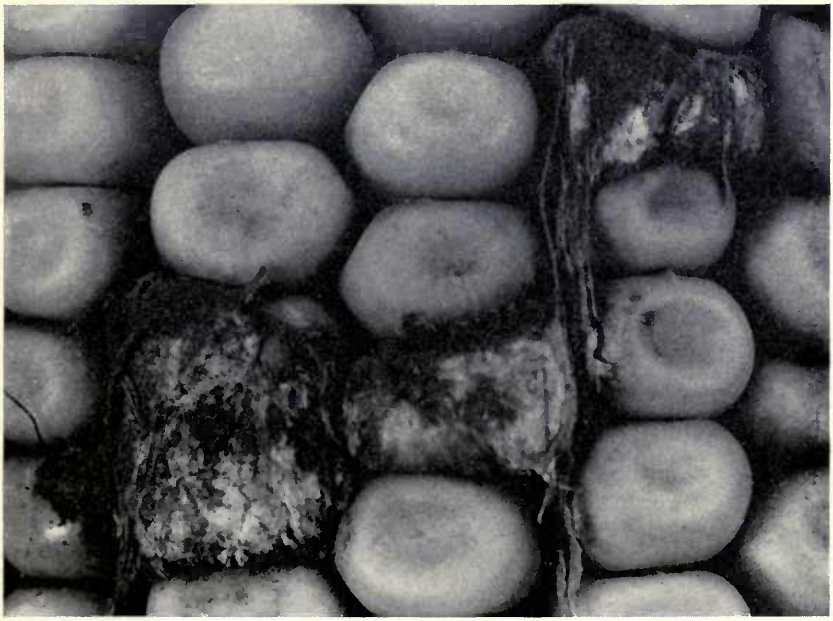


Kernels with white streaks caused by (A) *Fusarium moniliforme;* (B) *Cephalosporium acremonium;* (C) *Nigrospora oryzae.* The streaks are the result of air channels within the pericarp which break its transparency, hiding the yellow aleurone layer beneath. (Fig. 8) causes greater impairment in nutritive value and greater decrease in palatability (35).

Fusarium rot seldom involves the whole ear. It sometimes occurs at the tip of the ear only, often after mechanical injury by corn ear worms or birds. At other times it appears as rotted areas on other parts of the ear, usually in conjunction with local wet areas or feeding by ear worms or corn borers. Frequently it occurs as scattered rot-damaged kernels (Fig. 6). Such kernels may have had growth cracks or other pericarp injuries through which the fungus entered. Or the pericarps may have been sound, with the infection entering the kernels through the pedicels (25). In this case the fungus usually occurs in all kernels but the infection has developed to the rot stage in only certain ones.

The mycelium and spores of *F. moniliforme* are a pale salmon color, and rotted kernels sometimes tend to take on a pink or even reddish or purplish tinge. Spores develop abundantly on the rotted areas. In pure cultures, different strains of the fungus vary in colony appearance and in coloration produced in the agar medium.

Most of the Fusarium rot seems to start when the ears are quite



Fusarium moniliforme and Penicillium species growing on immature corn kernels whose pericarps had first suffered mechanical injury. (Fig. 9)

young, but after prolonged wet weather ear damage may also occur later, the symptoms frequently appearing as white streaks on the kernels of yellow corn (Figs. 7 and 8). These streaks are corroded channels within the pericarp caused by the fungus. Air in the channels breaks the transparency of the pericarp so that the yellow aleurone beneath cannot be seen (25). This fungus may continue to grow in the ears until the moisture content of the kernels is reduced to about 19 percent (24).

Sometimes *Penicillium oxalicum* or other Penicillium species become associated with Fusarium rot before the crop matures (Fig. 9). Experiments by the writer have revealed that in such associations *F. moniliforme* has penetrated the kernels more deeply than the Penicillium species. In stored mature corn, however, Penicillium species are more active because they have a lower moisture requirement.

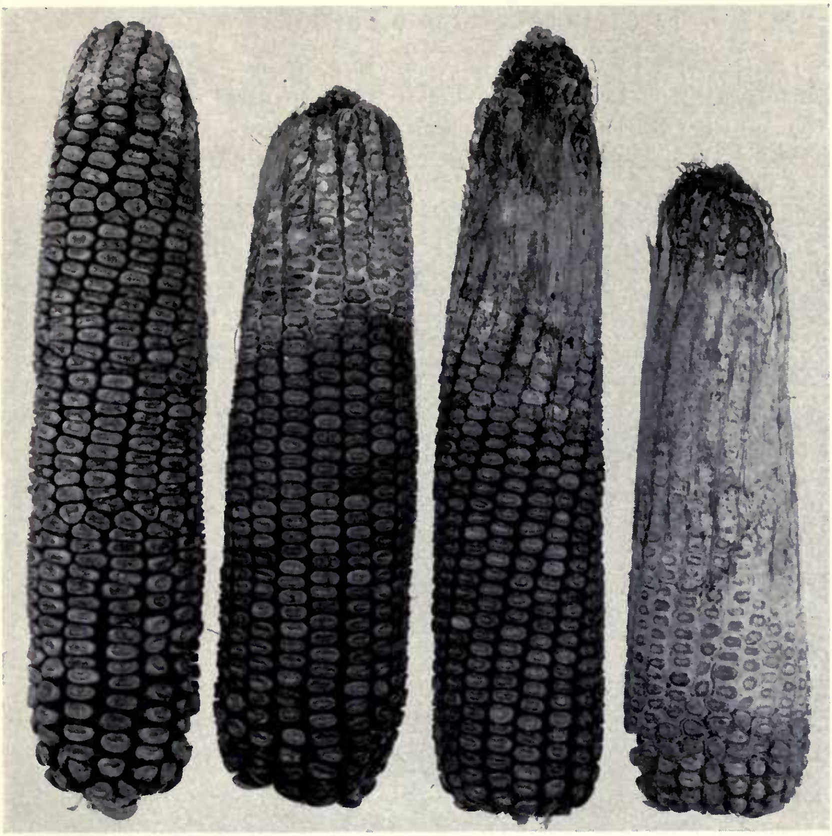
F. moniliforme can enter the live tissues of the corn plant, usually causing most damage to the ears. It is also the most common fungus found in lesions on corn stalks, both above and below ground. These stalk infections may begin before tasseling time. Except under certain environmental conditions or in a very susceptible host, however, this fungus is not an aggressive killer of the tissues, and thus would be classed as a weak parasite.

Gibberella Ear Rot

This rot, caused by *Gibberella zeae* (Schw.) Petch, has a reddish color and usually starts at the tip of the ear (Fig. 10). It rots all the kernels as it progresses, but seldom involves the whole ear. The reddish color is due more to the rotted kernels than to the color of the mycelium. In early infections the inner husks also become reddish, and the mycelium causes the husks to adhere to the ears. Spores of the fungus seldom are found on the rotted ears, but sometimes occur on the husks and shanks.

G. zeae may cause severe ear rot under some conditions. In Kenya, Africa, for example, it has been reported as the chief cause of corn ear rot (33). In America, Gibberella ear rot has usually been most prevalent in the Atlantic Coast states, according to data obtained for a number of years on corn ear rot damage found in shelled corn (17, 19).

In some years Gibberella ear rot is common in Illinois, and under unusual circumstances it has been the dominant ear rot in some Illinois corn fields (29). On the average, however, *G. zeae* is not responsible for much ear rot in Illinois. In this state the organism causes more damage as a stalk rot pathogen, readily producing both conidiaspores



Corn ear rot caused by *Gibberella zeae,* ranging from a small amount on the ear tip to a completely rotted ear. This rot nearly always starts at the tip end. Completely rotted ears are rare. (Fig. 10)

and ascospores on infected dead corn stalks under favorable weather conditions.

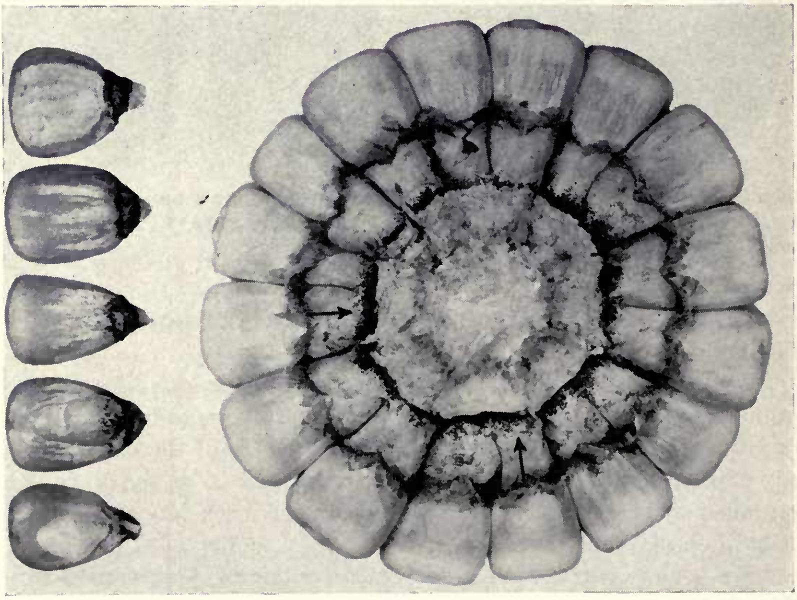
Corn ear inoculations with *G. zeae* and *Fusarium moniliforme,* made by the writer, have been reasonably successful in producing rot only when the inoculum was placed directly on the tip of the ear, and then only while the ears were very young. *Diplodia zeae,* on the other hand, continued to be aggressive as an ear parasite when inoculations were made at considerably later dates.

Like barley, wheat, and other grain containing scab caused by *G. zeae,* shelled corn containing Gibberella rot is toxic when fed to pigs or other nonruminants. They refuse to eat the grain when 10 percent or even fewer of the kernels are rotted.

Nigrospora Ear Rot

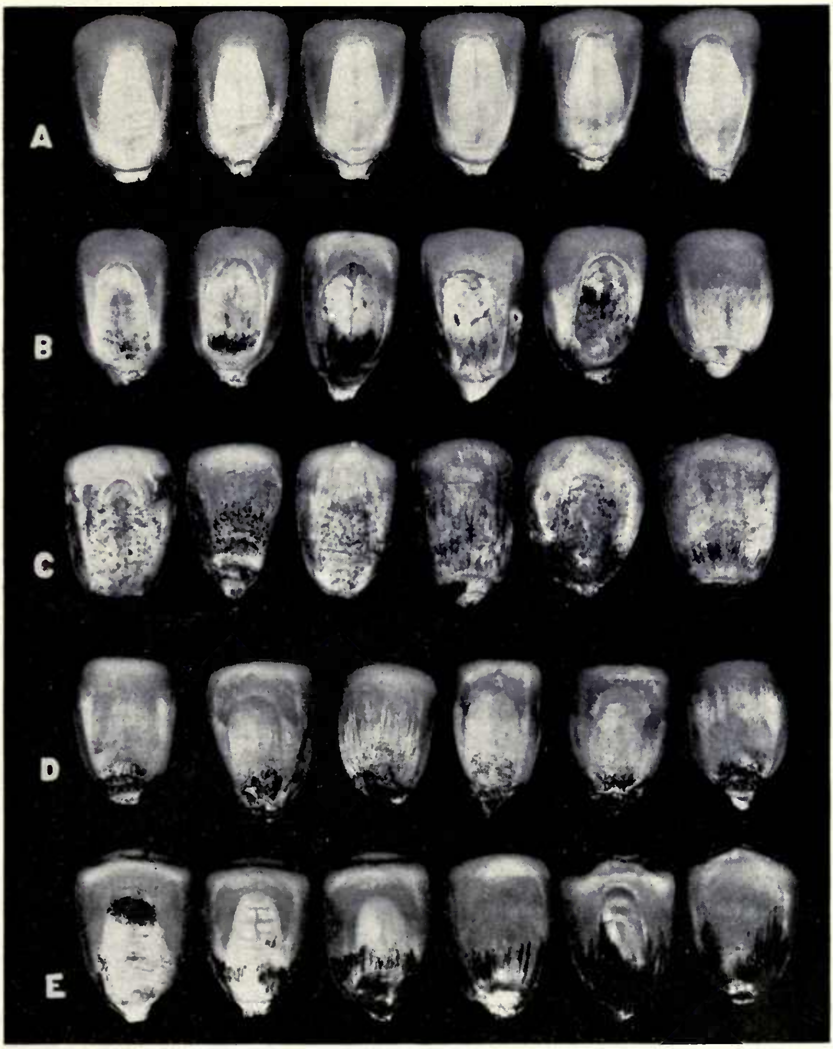
Ears severely infected with *Nigrospora oryzae* (B. and Br.) Petch, usually are light in weight. There is no conspicuous mold between the rows or over the surface of the kernels as in some of the other ear rot diseases. Infection may start at the tip or the butt end of the ear, usually the latter, resulting in a soft cob that is easily broken. The kernels are loose on the cob and show a bleached condition or whitish streaks, usually starting at the tips and extending toward the crowns (Figs. 8, 11, 12). When the rot is at the butt of the ear the cob appears shredded where the shank has broken off. Because severely rotted cobs and shanks are very easily broken, many ears may be knocked to the ground by mechanical pickers (9). The rot may also cause trouble in shelling because the cobs sometimes break up into small pieces.

After the rot is well established, spores become numerous and appear to the naked eye as black dots, serving as a good means of identifying the fungus. Actually, the dots seen with the naked eye are groups of spores (Figs. 11 and 12). When seen through a 10X magnifier, the individual spores are jet black bodies, appearing about the size of pin-



These kernels show the black spore masses of *Nigrospora oryzae* at the tip ends, as well as the whitish streaks characteristic of this rot. Spore masses (indicated by arrows) also appear as black dots on the broken ear. Single spores are microscopic in size. (Fig. 11) points. Under a compound microscope, the spores are seen to be nearly spherical or somewhat flattened in the proximal-distal axis.

When infection starts at the butt of the ear, the spore masses are first seen on the end of the cob surrounding the shank attachment; that is, on the sclerenchymatous glumes surrounding the central axis of the



Kernels in row A are sound and free from disease. The other rows of kernels have rots caused by various fungi: (B) *Diplodia zeae,* (C) *Physalospora zeae,* (D) *Nigrospora oryzae,* (E) *Hormodendrum* sp. (Fig. 12) cob. As the disease progresses up the ear, spore masses can be seen on the same kind of tissues when the ear is broken crosswise (Fig. 11), and the spores also appear on the tip ends of the kernels (Figs. 11, 12). When the infection is light, however, the only symptom may be a dull brown discoloration of the glumes on the surface of the tip or butt end of the cob after the ear is shelled.

In a study to determine the identity of this fungus, 50 spores from each of 102 Nigrospora-rotted ears were measured. The ears were collected from 1929 to 1938. Spores varied in size from 10 to 23 microns, but the variation found on any single ear was much less. The means per ear ranged from 13.9 to 18.1 microns. Despite the wide range in sizes, the distribution of size classes was such that spore size did not seem a valid basis for dividing the fungus into two species. As a result of these studies, the writer agrees with Stanton (47) on the nomenclature for this fungus, and combines all isolates under the binomial *Nigrospora oryzae.*

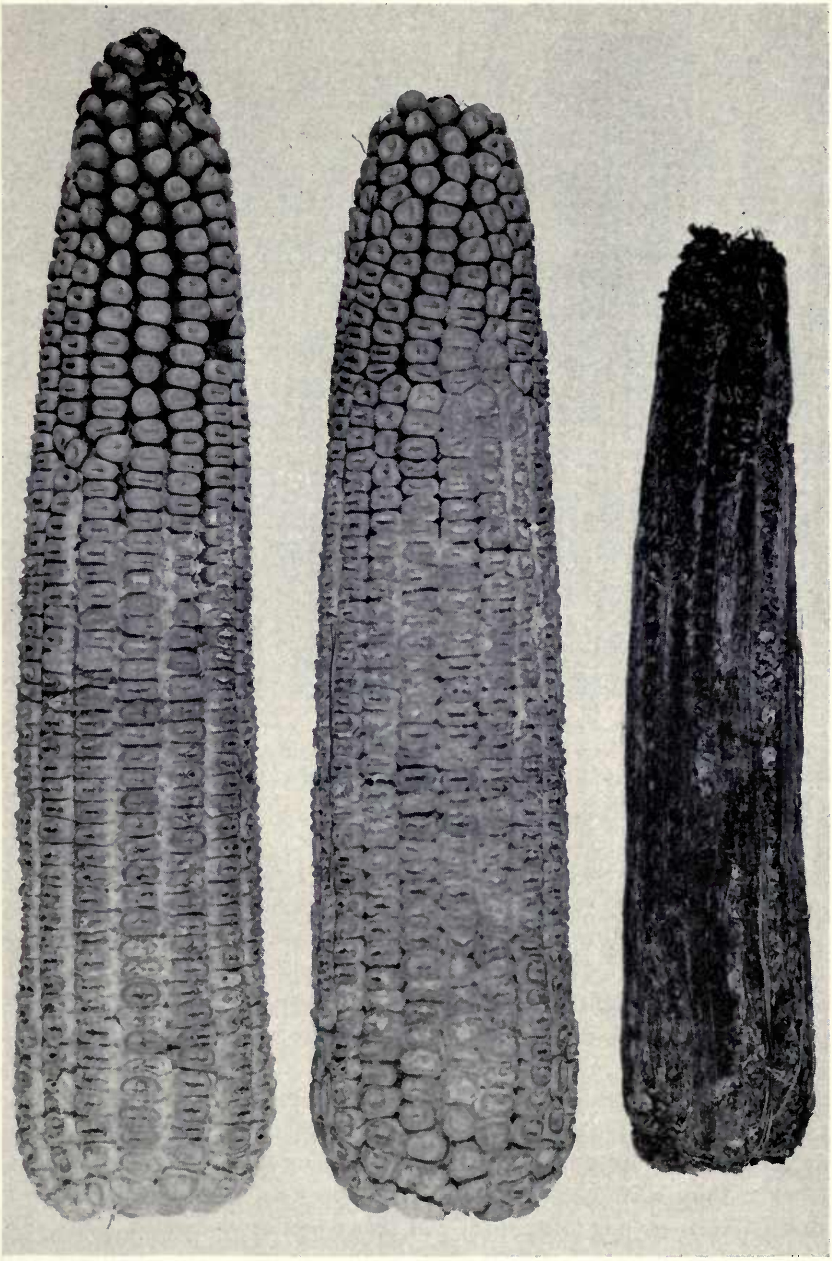
Susceptibility of corn ears has been shown to be associated with premature stoppage of translocation within the corn plant and low acidity of the cob (40, 48, 49) as well as the presence of other chemically unidentified substances favorable for the growth of the fungus (48). The disease is widely distributed and fluctuates widely in yearly prevalence but usually is not of major importance. *Nigrospora oryzae* is not an aggressive parasite but nevertheless it may cause considerable rot damage when corn plants have been injured by frost and the ears have not dried rapidly. Various other causes may also weaken or check the growth of plants prematurely and bring about conditions favorable for Nigrospora infection (9, 40, 49). The fungus very often rots rudimentary, axillary shoots and poorly developed secondary ears, producing many spores (49).

Hoppe (17) and Hoppe and Holbert (19), in studies of fungus infections in shelled corn produced east of the Rocky Mountains, found this disease common in all areas except the South and Southwest, but most prevalent in Minnesota and the Dakotas.

In feeding tests (36) it was found that, pound for pound, the nutritive value of Nigrospora-rot-damaged corn was very little different from that of sound corn.

Gray Ear Rot

Gray ear rot, caused by *Physalospora zeae* Stout, has many superficial resemblences to Diplodia ear rot, especially in the early stages of infection or in late infections that become arrested before the rot has progressed very far. Similarities to Diplodia rot are: (a) The green



Gray ear rot caused by *Physalospora zeae.* Late infection as in the ear on the left may resemble Diplodia rot. Early infection (right) results in black mummified ears. (Fig. 13)

Early infection with *Physalospora zeae* results in a dark gray to black mold covering the ears, and little black dots, apparently sclerotia, in the husks. These sclerotia may also appear on the kernels of ears not so severely rotted, as in Fig. 12C. (Fig. 14)

husks become blanched while the ears are still young, (b) the mycelium is at first white, (c) the rot usually starts at the butt of the ear but may also start at the tip, and it involves all the kernels as it progresses, (d) when the butt of the ear and shank are rotted, the ear breaks off in a shredded manner, (e) the fungus growth causes the husks to adhere to the ear, and (f) early infections may result in lightweight mummies (Fig. 13).

After gray rot has made considerable progress, it may be distinguished from Diplodia by the presence of tiny black sclerotia that appear first in the germ area but later occur on much of the kernel surface (Fig. 12C). Soon after they appear on the kernels they can also be seen in the interior of the cob when it is broken crosswise, and on the husks (Fig. 14). These sclerotia are very small but can be seen with the naked eye. When viewed through a 10X magnifier, they are irregular in shape.

Other ways in which gray rot differs from Diplodia rot in advanced stages of development are: (a) Kernels may take on a streaked to more or less solid slate gray to black color, whereas rot caused by *D. zeae* appears in various shades of brown, (b) the husks turn dark gray, (c) the felty mycelium on the surface of the ear and between the rows of kernels becomes a darker gray than on Diplodia-rotted ears, and (d) mummies are nearly black (Figs. 13, 14). The fungus does not usually remain viable in the host tissue for more than a year (55), whereas *Diplodia zeae* remains viable for several years.

Physalospora zeae grows rapidly on potato dextrose medium in Petri dishes. At first it is white but after 4 or 5 days it becomes a zonated dark bluish-gray. *Diplodia zeae,* on the other hand, remains white. Neither fungus is likely to form fruiting bodies under these conditions and definitely not within the time mentioned.

In 1942, 6 percent of the ears in part of a Lawrence county field were observed by the writer to be rotted by *Physalospora zeae.* This was the first recorded identification of gray ear rot in Illinois, but a 1909 photograph of diseased corn kernels collected by T. J. Burrill near Urbana, Illinois, clearly shows the symptoms of this disease.

Ullstrup (55) found a field in Indiana where 10 percent of the ears were rotted by Physalospora. This disease is now known to occur over most of the eastern half of the United States (59), but it is comparatively rare. The same fungus also attacks the leaves of corn (52, 55).

Penicillium Rot

In the field, Penicillium mold usually occurs primarily on ears that have been injured by corn ear worms or other causes. The mold is most likely to occur on the tip ends but may be found on other parts of the ears. Several species of Penicillia are involved, none of them being very active parasites. *P. oxalicum* tends to appear as a grayish blue-green mold, while some other species may be a brighter bluish-green. All species produce an abundance of spores, which dust off easily. As mentioned earlier, Penicillia often occur in conjunction with *Fusarium moniliforme,* but at times they develop on ears independently.

Penicillia also cause the storage rot known as "blue eye." In this case the fungus may enter the kernels without the benefit of previous mechanical injury to the pericarp. It grows in the germ, and fruits beneath the pericarp covering the germ area, giving this area a blue-green color (Fig. 15). According to different investigators (13, 24, 41), blue eye can take place at grain-moisture contents as low as 14 or 16.7 percent. The lower limit for growth of the fungus would

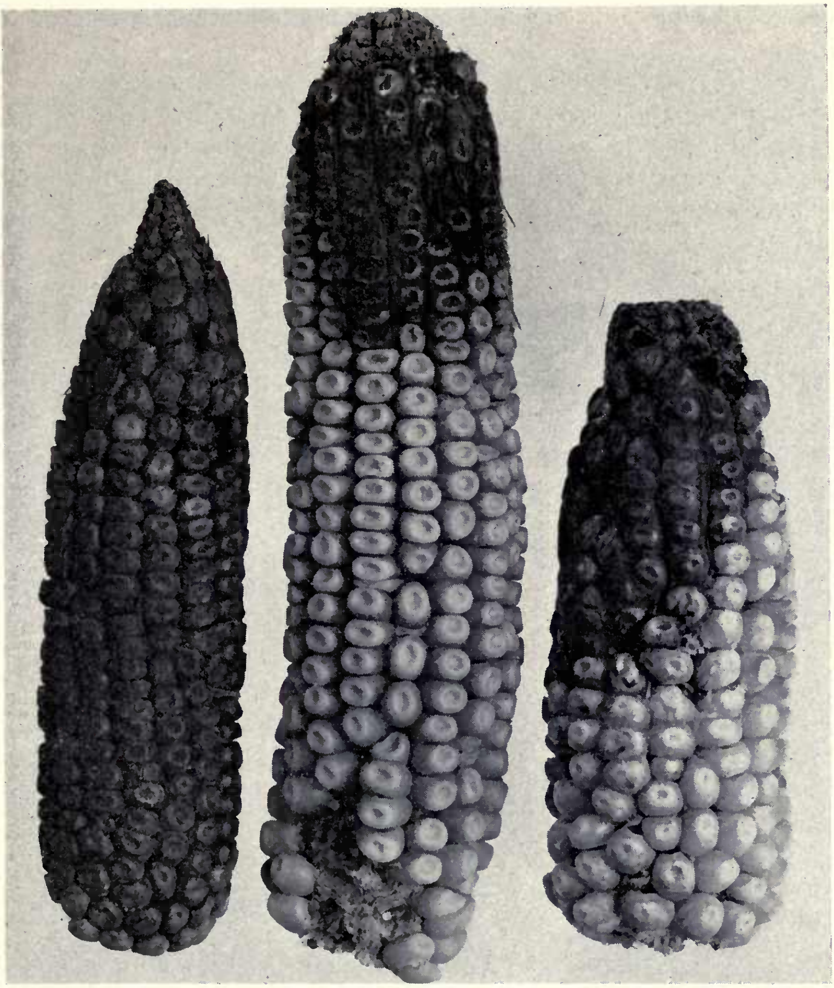
"Blue eye," primarily a storage rot, is caused by Penicillium species, which grow and sporulate on the germ beneath the pericarp. (Fig. 15)

depend on a number of things, including the species and strain of the fungus, temperature, and length of time in storage. Furthermore, the percentage of moisture found in the grain depends somewhat on the test method that is used.

Black Ear Rot

Ears damaged by black ear rot look as if they have been charred by fire (Fig. 16). The kernels are black because they have been invaded by a black fungus and the black mycelium fills the spaces between the rows of kernels. This ear rot, caused by *Helminthosporium carbonum,* Ullstrup, was first reported from Tennessee (43, 44), where it was observed in 1931 in some corn inbred lines. Since then it has occasionally been observed on certain inbreds in Indiana (58), Illinois, and other places.

There are two races of the fungus but they cause the same symptoms on the ears. Race I is the more virulent on susceptible plants, but susceptibility, as far as is known, is limited to four inbreds, Pr, K44, K61, and Mo21A (58). Resistance is dominant and therefore crosses involving susceptible and resistant inbreds are resistant. Race II is less specialized in its parasitism, and no dominance in resistance or susceptibility is apparent. Both races also cause leaf blight, and Race II can often be found fruiting at the nodes of mature corn stalks of commercial hybrids.

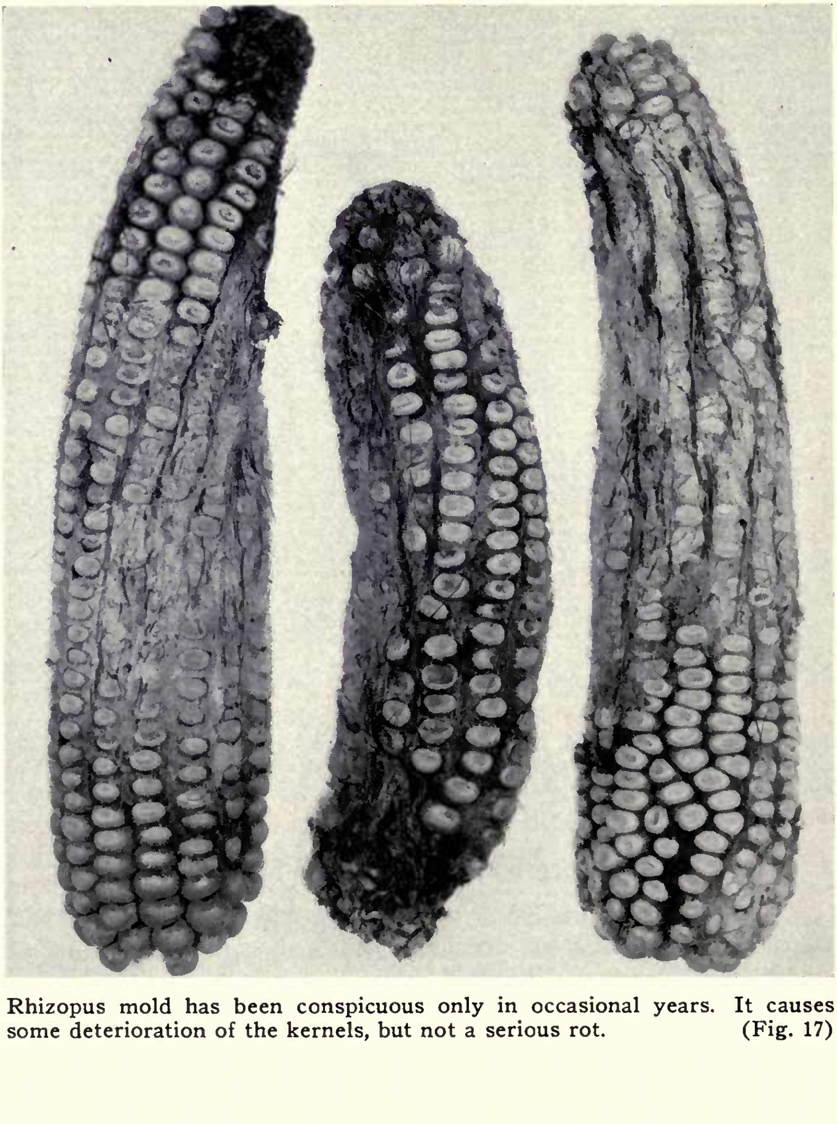


Black ear rot caused by *Helminthosporium carbonum* Races I or II, on inbreds Ia. Pr (left); CI. 187-2 (center); Ind. P8 (right). This rot also occurred on Ind. WF9 in the same field. The two races cannot be distinguished by appearance of the ear. (Fig. 16)

Hormodendrum Kernel Rot

Unless the pericarp has been broken at the crown, ears having Hormodendrum kernel rot usually do not show signs of it until they are shelled. Ordinarily the black color shows first near the tips of kernels and develops toward the crown in a more or less streaked manner (Fig. 12E). Hoppe (18), however, has reported instances of the rot starting at the crowns, having gained entrance through growth cracks.

As has been reported (30, p. 150; 37, pp. 64-65), this disease has been observed in occasional years in Illinois for a long time. It has occurred in both commercial open-pollinated varieties and various hybrids. Occurrence seems to have been coincidental with early frosts, although the frost damage was not necessarily severe enough to kill the seed.



Rhizopus mold has been conspicuous only in occasional years. It causes some deterioration of the kernels, but not a serious rot. (Fig. 17)

Rhizopus Ear Mold

This fungus appears as a white mold on the ears and in some stages has a superficial resemblance to *Diplodia zeae*. Usually the difference is quite clear, however, because on close inspection many dark dots on the mold are just visible to the naked eye. Sometimes they are so numerous that the fungus has a peppery-gray appearance (Fig. 17). These dots are the sporangia of the fungus and are filled with many spores. Kernels removed from such ears do not show much discoloration. The germ area may take on a slightly smoky opalescence, and the embryo may be weakened or in extreme cases even killed. The species of Rhizopus involved has not been identified.

This fungus appears on corn ears only under certain weather conditions. It was especially common on open-pollinated varieties and hybrids in many parts of Illinois in 1936, following a hot, dry summer. From 1931 to 1935, Boewe (1), in ear-rot surveys of many Illinois cornfields, found that the annual percentage of ears infected with Rhizopus varied from 1 to 6.8. Others (17, 19) have noted the occurrence of Rhizopus and Mucors in market corn, especially that from the western part of the Mississippi valley.

Aspergillus Rot

The Aspergilli most commonly appear as black, greenish-yellow, and green molds which can be identified as *Aspergillus niger* Van Tiegham, *A. flavus* Link, and the *A. glaucus* group, respectively. However, other Aspergillus species also have been reported as causing deterioration of corn kernels (24, 41).

Black and greenish-yellow growths of Aspergilli appear on ears in Illinois cornfields in some years but ordinarily are of very little importance before harvest. *Aspergillus niger* has sometimes been found scattered over the whole ear, giving it a sooty appearance, but *A. flavus* has usually been observed only at the tip end. All three of the Aspergillus species mentioned are common in stored ear or shelled corn when the moisture of the corn has been too high for safe storage, and they may cause much damage. Of all fungi attacking corn in storage, strains of the *A. glaucus* group have the lowest water requirement.

Taubenhaus (63) observed in Texas that *Aspergillus niger* was most common in cornfields in dry years while *A. flavus* was the most common in years when moisture was more plentiful. Melchers (34) found Aspergillus species, primarily *A. niger,* very prevalent in Kansas seed corn, and found an exceptional amount on dent corn and popcorn ears in the unusually dry season of 1953. During 1937 to 1941, according to Hoppe's reports (17) on fungi found in rot-damaged corn in 16 or more scattered states east of the Rocky Mountains, the highest percentages of Aspergillus occurred 4 years in Texas, and 1 year in Kansas.

Feeding tests of moldy shelled corn from a steel bin were made with pigs (12). The grain was 100 percent moldy, with *Aspergillus niger* and various species of *Penicillium* predominating. The 10 pigs fed on sound corn gained considerably faster than the 10 fed on moldy corn, but all of them remained healthy in appearance. It was calculated that in this test a pound of moldy corn had 68 percent of the feeding value of a pound of sound corn. Moldy corn often differs greatly in the kinds of mold involved. It no doubt differs also in feeding value, and in some cases may even be toxic.

METHODS OF EXPERIMENTATION, GENERAL

Corn Varieties Used

Early experiments, beginning in 1924, were conducted with open-pollinated dent varieties. From 1935 through 1940, some hybrids were included in the tests, and since 1941, experiments have been entirely with hybrids. The data on hybrids were obtained from naturally pollinated ears.

Field Plots

Plots for ear rot determinations usually were 2 x 10 hills in size, at the rate of 4,000 hills per acre, and were replicated 4 to 10 times. Unless mentioned otherwise, the tests were conducted in the rotation systems of the Agronomy South Farm, Urbana, on a dark brown silt loam having a good, but not exceptionally high, fertility level. Harvesting was usually done near mid-November when the moisture content of the grain was from 25 to 13 percent. Moisture content varied somewhat with the varieties used but more with seasonal conditions.

Ear Examinations for Rot Prevalence

From 1924 to 1949, ears were sorted on the basis of ear symptoms. At first this method was used exclusively, but after 1941, the kernel-examination method was used except for some of the ear-inoculation experiments. When infections occurred naturally, the ears from each replicate were weighed and then poured onto a sorting table (Fig. 18). In years when concealed Diplodia rot was common (Fig. 2)

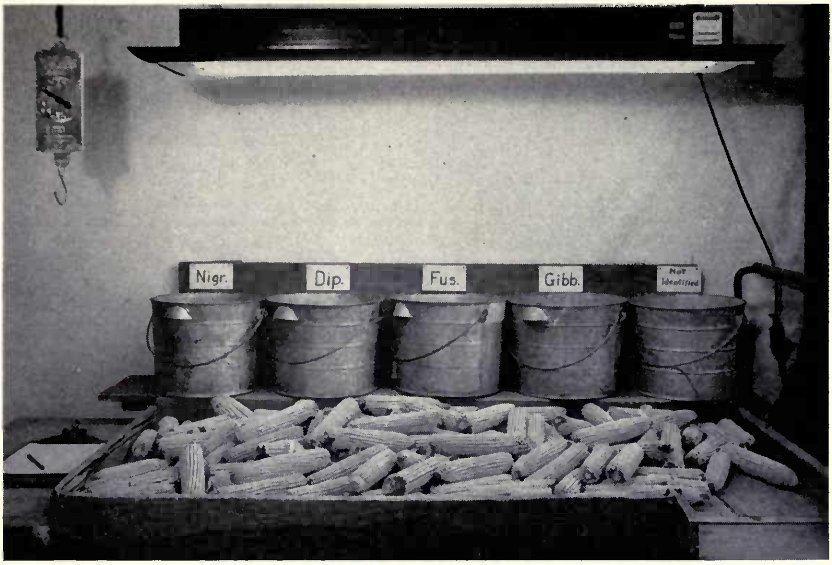


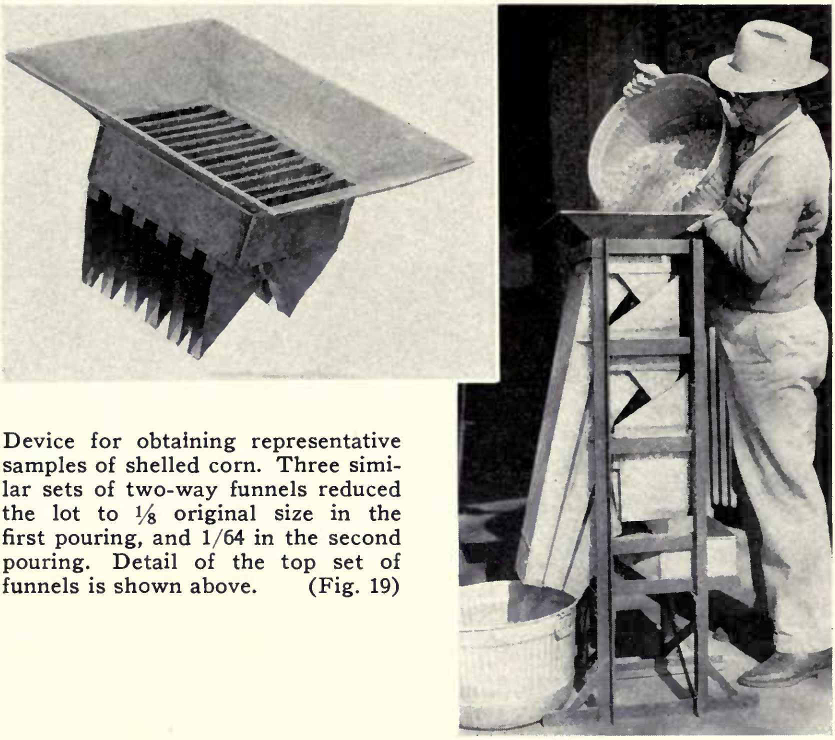
Table used when sorting ears for determinations of rot damage by weight. The pointer on the balance was adjusted for tare, all the pails having been adjusted to equal weights. (Fig. 18)

it was necessary to remove some kernels for examination from every ear that did not have a healthy-appearing butt. For some ear-inoculation tests (Tables 8, 9, 11, 12, 14, 15), results were based on ear counts but in all other tests they were determined by ear weights.

Making determinations by weight rather than count had the advantage that partly rotted ears could be broken and the sound part separated from the rotted part. Ears with fewer than 10 rot-damaged kernels were considered sound. To facilitate weighing, five half-bushel measures with bail were adjusted to equal weights and the tare accordingly adjusted on the spring balance (Fig. 18). A 4-foot fluorescent light fixture was hung 40 inches above the sorting table.

Kernel Examinations in Shelled Corn

Sampling and sorting kernels. Beginning in 1933, some rot determinations were made on the kernel basis rather than the ear basis. All the ears, sound and rot-damaged, from each replicated plot were shelled and a 200-to-500-gram sample of shelled corn was taken. The sampling device used, which was designed by the writer, consists of three sets of two-way funnels that reduce the sample to one-eighth original size at each pouring (Fig. 19). Kernels with discoloration that clearly indi-



Device for obtaining representative samples of shelled corn. Three similar sets of two-way funnels reduced the lot to ⅛ original size in the first pouring, and 1/64 in the second pouring. Detail of the top set of funnels is shown above. (Fig. 19)

cated an unhealthy condition were separated from the sound kernels, and the percentage was determined by weight. A discussion about this method has been published by Hoppe and Holbert (20). It is essentially the method employed by the Grain Division of the Agricultural Marketing Service, U.S. Department of Agriculture, for determining "total damage."

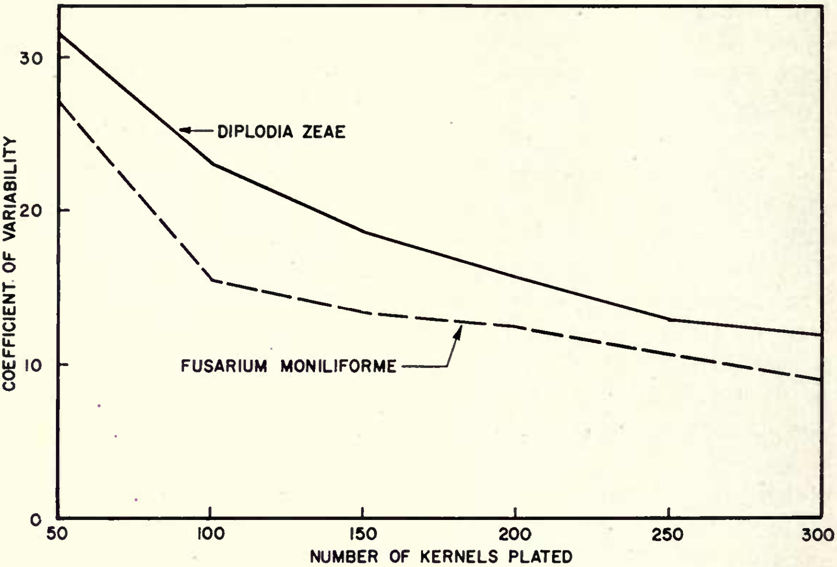
To insure that both sides of each kernel were examined, a device was made on which a quantity of kernels were spread out one kernel deep, and after all kernels had been examined, they were turned over in one operation and then examined on the other side. This process gives information on the amount but not the kind of rot damage.

Sorting errors. The human error involved in determining total rot damage was studied by comparing the work of two conscientious assistants. To give them a guide for classifying borderline kernels, W. B. Combs of the Agricultural Marketing Service, U. S. Department of Agriculture, Chicago, was asked to separate a group of slightly discolored kernels according to official standards. These kernels varied somewhat in degree of discoloration, but all approached the borderline between healthy and damaged corn. After classification, the kernels were placed in two rows in a Riker mount. One row was labeled, "grading damaged," and the other, "grading undamaged."

A field experiment comprising six hybrids and seven replications of each was harvested and shelled, producing an average of about 1 bushel shelled corn per replicate. This corn was reduced to samples of about 250 grams each, with the sampling device (Fig. 19). Assistant A determined the percent of rot-damaged kernels in each of the 42 samples. The damaged kernels were then replaced and mixed with the samples from which they had been removed, and the same assistant was asked to sort them again without knowledge that he had done them before. In the first sorting he found an average of 4.126 percent damaged kernels; the second time, 4.177 percent. The correlation coefficient between the two trials was .992. With this assistant, the personal error in doing the job was practically nil.

Next the same 42 samples were sorted by Assistant B, again without knowledge that they had been done before, and with the same set of standards before him. He found an average of 3.467 percent of rot-damaged kernels and the correlation coefficient between the work of A and B was .827. Not only was there a significant difference between the two assistants in total amount of damage found, but the correlation in amount of damage found in each of the 42 samples was not as high as might be desired. For this reason, the policy was followed of either letting one person do all the sorting on one experiment, or if more people were involved, having each one do all the treatments or varieties, and dividing the work by replications.

Size of sample. Hoppe and Holbert (20) have shown that at least a 200-gram sample is necessary for determining total rot damage. For information on specific rot damages, the kernels must be plated and the fungi examined. No information was available on size of sample needed for this purpose. In order to obtain data on accuracy in relation to size of sample, some shelled corn containing about 4 percent rot discoloration caused primarily by *Diplodia zeae* and *Fusarium moniliforme* was mixed well and subdivided with a Boerner divider into 120 samples of 250 grams each. These samples yielded 50 or more rot-damaged kernels, and 50 of such kernels were plated from each sample. The results from the 50-kernel samples were combined to obtain the coefficient of variability for lots of 50, 100, 150, 200, 250, and 300 kernels. The results (Fig. 20) indicated that, wherever possible, 150 rot-damaged kernels should be plated per sample. In order to obtain a

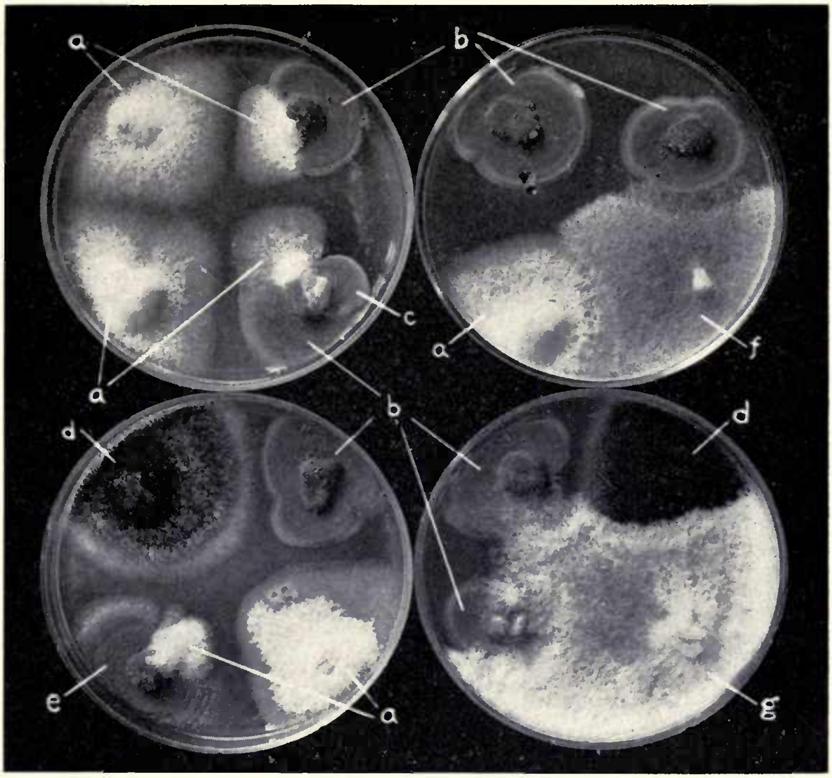


Coefficient of variability for *Diplodia zeae* and *Fusarium moniliforme* in rot-damaged kernels sorted from shelled corn, in relation to number of kernels plated for identification purposes. (Fig. 20)

number approaching this size, samples of shelled corn were increased to 500 grams for each field-plot replication unless rot damage was unusually high.

Fungus identification. The fungi within the kernels, presumably the cause of the rot or discoloration, were determined by plating the kernels on potato dextrose agar medium under aseptic conditions. The surface of the kernels was first sterilized with calcium or sodium hypochlorite. Since the strength of these chemicals varies with age and other factors, the dilution used was determined by preliminary biologic tests. The aim was to use a concentration just adequate for removing surface contaminants. However, completely rotted kernels sometimes soaked up so much disinfectant that all fungi were killed and the kernels appeared to be sterile. At other times some discolored solid kernels (usually dead) also gave a sterile reading.

The culture plates were examined after incubation for 5 days at room temperature (Fig. 21). Fungi that could not be identified at that time were transferred to agar slants for further study. Kernels that produced no fungus colonies were split open with a sterile scalpel and replated on fresh agar. Even then, some discolored kernels failed to produce mold growth.



Fungi isolated from rot-damaged shelled corn: (a) *Fusarium moniliforme,* (b) *Penicillium oxalicum,* (c) an unidentified Penicillium, (d) *Aspergillus niger,* (e) *Aspergillus flavus,* (f) *Nigrospora oryzae,* (g) *Diplodia zeae.* (Fig. 21)

Most of the fungi could be identified with the naked eye. Of those that couldn't be identified in this way, some were studied under the Ultropak microscope, so that spores on the fungus colonies could be examined without disturbing them; water mounts were made of others for the usual kind of microscopic examinations. Kernels sometimes produced two or three kinds of fungi (Fig. 21), in which case all of them were recorded. Single spore cultures were not made for routine identifications.

Statistical Interpretation

The significance of results was measured by the use of the analysis of variance. Where advisable, to obtain a more precise interpretation, percentage figures were converted to angles (arc sin square root of the percentage). Where this has been done, no figure for least significant difference (L.S.D.) is given, but a significant difference at the 5-percent level is indicated by a star, and a significant difference at the 1-percent level by two stars. For some data correlation coefficients were calculated. These coefficients may be positive, when the two variables move in the same direction, or minus when they move in the opposite direction.

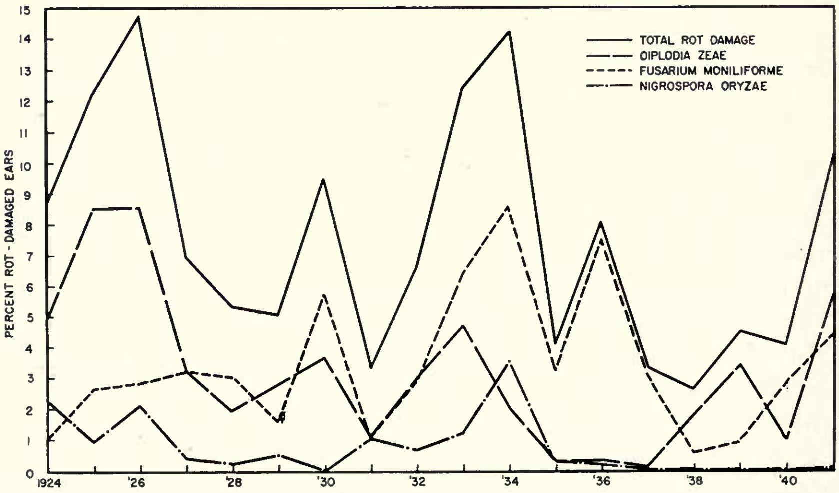
The term "significant" is used herein to indicate that the chances were at least 19:1 that the difference found was real and not due to experimental error (5-percent level of error). "Highly significant," indicated that the chances were at least 99:1 that the results were not due to error (1-percent level of error).

PREVALENCE OF CORN EAR ROTS IN ILLINOIS

Results Based on Examination of Ears

Data on specific kinds of ear rot were obtained from two open-pollinated varieties grown in several crop rotation systems on the Agronomy South Farm, Urbana, 1924 to 1941 inclusive. Rot percentages were based on weight. Details of procedure have been given under the heading of "Methods of Experimentation" (page 26).

The results are shown in Fig. 22. Some years were particularly favorable for Diplodia rot, others for Fusarium rot. The former was

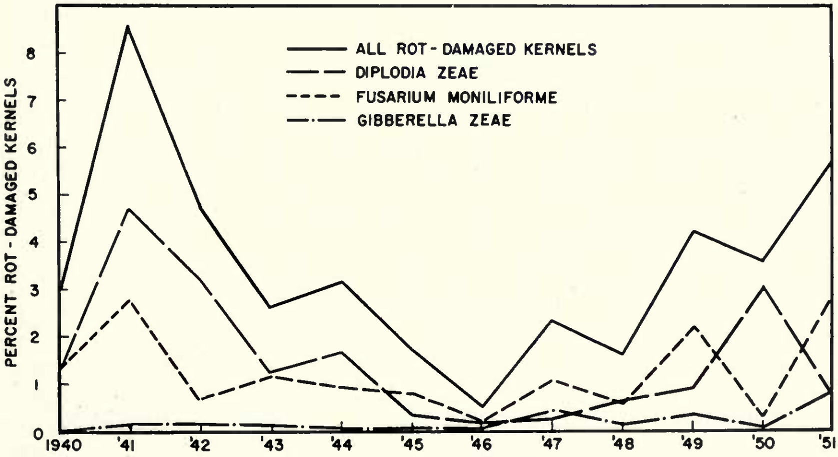


Annual variations, 1924-1941, in ear rot damage caused by various fungi in two open-pollinated varieties at Urbana. Determinations were made by ear symptoms. (Fig. 22) most prevalent seven times and the latter nine times during the period. Even though partially rotted ears were broken and the rotted part separated from the unrotted part, a detailed study of the rot-damaged ears on the kernel basis indicated that the values obtained for Fusarium were a little high while those for Diplodia were more nearly correct. Nigrospora rot exceeded 1 percent damage five times during the 18-year period; Gibberella rot exceeded it only once.

Boewe (2) has published data obtained independently on the prevalence of Diplodia ear rot in the state as a whole for 1928 to 1937 inclusive. The correlation between his results and the results shown in Fig. 22 is very high, although Boewe's percentages are somewhat lower. The difference can probably be ascribed to a difference in methods. He obtained his data earlier in the season, directly in the field before harvest, and generally without removing the ears from the plant.

Results Based on Examination of Shelled Corn

From 1940 to 1951 inclusive, ear-rot prevalence was determined on the basis of fungi isolated from rotted or discolored kernels in shelled-corn samples. The values (Fig. 23) are an average of four or more hybrids planted each year in several locations on the Agronomy South Farm, Urbana. During the 12-year period, Diplodia rot was considerably more prevalent than Fusarium rot four times, and the reverse also occurred four times.



Annual variations, 1940-1951, in ear rot damage caused by various fungi in several hybrids at Urbana. Determinations were made by sorting shelled samples and using laboratory methods for isolating and identifying the fungi involved. (Fig. 23)

The data for 1940 and 1941 overlap the data shown in Figures 22 and 24, which were obtained with different varieties and different methods. All three sets of data show that much more rot occurred in 1941 than in 1940. From the high point in 1941 there was a general downward trend until the occurrence of rots was at an exceptional low in 1946, after which there was an upward trend until 1951. The high point in 1951, however, was a local occurrence. Data from six Illinois Corn Performance Tests (Illinois Corn Tests) in other parts of the state all showed lower prevalence. At all locations Fusarium rot was considerably more prevalent than Diplodia rot that year.

Data on total rot damage from the Illinois Corn Tests, based on kernel separations, were obtained at a number of locations from 1935 through 1952.[a] During the first 6 years, five adapted open-pollinated varieties were included in each test. Hybrids, in general, were no more resistant to ear rot than the open-pollinated varieties. No similar comparisons have been available since that time, but hybrid U. S. 13, which is still considered to be a good hybrid, was entered in the Illinois corn performance tests as early as 1938, which means it was compared with the open-pollinated varieties over a 3-year period. In 14 experiments during that time the average percentage of rot-damaged kernels for this hybrid was almost exactly the same as for the open-pollinated varieties (Illinois Agricultural Experiment Station Bulletins 450, 463, and 474).

Reports From Terminal Markets

Valuable data on the prevalence of ear-rot damage may be obtained from licensed grain inspectors (50). Until recent years, the percentage of June receipts of corn with more than 5 percent damage appears to have been a reliable index of the amount of rot during the preceding season. By June the corn is dry enough that moisture and test weight are unimportant as grading factors. The grade then is determined primarily by the factor called total damage, which in turn is governed primarily by rot-damaged kernels.

As a result of the efforts of Neil Stevens, former head of the Botany Department, University of Illinois, data are available on the percentages of carloads of various grade classes received at Illinois markets in June of each year 1916 to 1941 inclusive. Only data from terminals receiving 50 or more carloads in June were used and Chicago was omitted because much of the corn received there originates from

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[a] No tests were made in 1942 because of gasoline shortage and other stress due to war conditions.

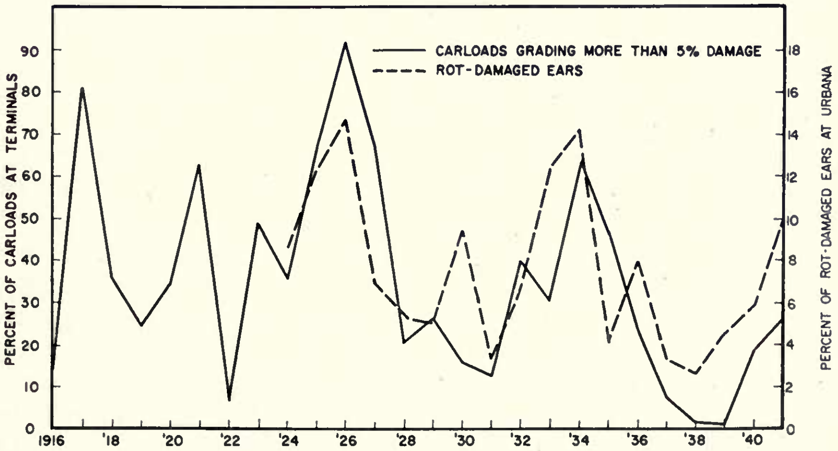
other states. The number of qualifying terminals ranged from two to five per year.

Since 1934, the percentage of cars grading more than 5 percent total damage, has been the basis for comparing relative amounts of rot damage between years. Previous to that time, due to different grading standards, the figures for more than 4 percent and more than 6 percent were averaged to obtain an approximation for the "more than 5 percent" level. Because of the change in grading standards, the term "more than 5 percent damage" is used rather than designating a commercial grade number.

Regardless of the period of time involved or the method of securing data, there were remarkable variations between years in the percentage of cars grading more than 5 percent damage (Fig. 24). There also seemed to be a tendency for ear rots to become less important during certain successive years and to increase during others, with some indication of high points occurring in cycles.

Greatest damage occurred in 1926. In that year the September rainfall, as a state average, was 9.68 inches, an all-time high. The combined rainfall for August, September, and October also was the highest on record.

Rot damage was very low in 1938 and 1939. By 1938, 47.5 percent of the corn acreage in Illinois had been planted to hybrids, and in 1939 the precentage rose to 65.5. It appeared to some that, with the use of



Annual variations in (1) the percentage of carloads of corn, received during June at a number of Illinois terminals, that graded more than 5 percent total damage, 1916-1941; and (2) the percentage of rot-damaged ears in corn grown at Urbana, 1924-1941. (Fig. 24) hybrids, the ear-rot hazard was becoming negligible. However, while the percentage of corn land planted to hybrids continued to increase steadily, the amount of ear rots began to climb again (Fig. 24).

The high prevalence of rot in 1941 caused the seed producers much trouble. In that year the average October rainfall in Illinois was 9.14 inches, the highest on record for the month. Some seed fields were not harvested until December, and some were abandoned for seed purposes.

In recent years corn has often been stored on the farm for more than a year before it goes to market. Therefore, records of commercial grades in June would no longer give reliable data on the conditions of corn in the previous year unless the history of each carload were available.

A comparison of methods. In Figure 24, the curve for total rot damage found at Urbana by the ear-examination method is superimposed on the curve for percentage of carloads grading more than 5 percent damage in June. Although the methods used are drastically different, and the one curve represents Illinois as a whole while the other represents only one location, there is a remarkable similarity between the two curves. The differences that exist could easily be expected from differences in location alone if the methods had been the same. The general similarity of results indicates that both methods are reliable. Stevens and Wood (51) had reported a somewhat similar agreement between methods for a shorter period of time but a larger geographical area.

A recent 5-year average. While June deliveries of market corn are no longer closely related to production in the previous year, a 5-year average can be used as representing the 5, 6, or 7 years just previous to the last year in the average. The average for June deliveries at 10 terminal markets in Illinois for 1953-1957 inclusive are given in Table 1.[a] Practically all the corn received at the nine terminal markets outside of Chicago was produced in Illinois. Within this group, 16.1 percent of the cars graded numbers 3, 4, 5, or sample. These grades rated thus primarily because they had more than 5, 7, 10, or 15 percent damaged kernels, respectively. When Chicago is included, the percent of cars within this grade group is 20.8 percent.

Average rainfall for August, September, and October was below normal in every growing season represented by these data. As will be shown later (page 39), these are the months for which rainfall is most strongly correlated with ear rots. As a very small portion of the corn

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[a] Data on carload receipts by grades were received from Hazen P. English, Grain Division, Agricultural Marketing Service, U. S. Department of Agriculture.

may have been grown as early as 1950, we may examine the total 3-month average deficit for 1952-1956, 1951-1956, and 1950-1956. These are −1.93, −1.48, and −1.47 inches, respectively.

The average of 16.1 percent of cars grading more than 5 percent damage can be compared directly with the annual values given in Figure 24. The most recent year with a similar percent in this chart is 1930 (15.7 percent). That year, the total rainfall deficit for August, September, and October was −1.73 inches. Thus, there is a surprisingly close parallel between the amount of damage and amount of rainfall for these two periods, separated though they are by 20 to 26 years. Unless some environmental or management factor has become operative to increase ear rots in the meantime, it would seem that no progress at all has been made to improve the ear-rot resistance of the corn in common use.

FINANCIAL LOSSES FROM CORN EAR ROTS

In Table 1 is included an estimate of the average dollar loss that rot damage caused in corn marketed in Illinois in June, 1953-1957. Discounts actually were a little higher than indicated in the table.

Table 1. — Carloads of Corn and Approximate Price Discounts Caused by Rot Damage in Each Commercial Grade Received in June at Various Terminal Markets in Illinois

(5-Year Average, 1953-1957)

Commercial grade	Number of cars in June	Discount per bushel	Discount for cars received in June
For 9 Illinois Terminals, Excluding Chicago			
		cents	*dollars*
1	1,233	0	0
2	1,436	0	0
3	181	1.2	4,200
4	78	3.5	5,320
5	37	6.0	4,440
Sample	215	12.0	51,600
Total	....	....	**65,560**
For 10 Illinois Terminals, Including Chicago			
1	2,060	0	0
2	2,563	0	0
3	406	1.2	9,744
4	218	3.5	15,260
5	129	6.0	15,480
Sample	465	12.0	111,600
Total	....	....	**152,084**

Lower figures were used to make allowance for a few carloads that may have graded low for reasons other than rot damage.

To estimate the loss for corn grown in Illinois, we can start with the $65,560 loss at the nine markets outside of Chicago. Assuming that about 40 percent of the corn marketed in Chicago was also grown in Illinois, there is an additional loss of $34,600. These figures are for June only. About the same amount of rot damage occurs in May, July, August, and September as in June, making a total loss of more than $500,000 in corn marketed during these 5 months. In addition, many carloads grade poorly because of damaged kernels in other months.

At least 50 percent of Illinois corn has not been marketed but has been fed on the farms. It has been clearly shown (12, 21, 35) that the feeding value of corn may be impaired by rot damage. Therefore, it can be estimated that the total loss from corn ear rots averaged about 1¼ million dollars per year during the 5 years studied.

As all these calculations and estimates are based on a period when the mean rainfall during the critical months was, in general, below normal, the average annual loss from ear rots in Illinois may be conservatively estimated as around 1½ million dollars.

FACTORS INFLUENCING NATURAL ROT DEVELOPMENT

Rainfall

That moisture conditions influence the development of corn ear rots has been known for a long time (3, 8), but the data presented here give a more precise measurement of this relationship than has heretofore been available. Between 1916 and 1952 corn ear-rot data were taken in Illinois for four different periods (Table 2). A uniform method of collecting data was used within each period. The periods covered 18, 12, 18, and 26 years, overlapping somewhat and providing a continuous record. Data were obtained on specific rots during two of these periods, covering a span of 28 years. The other data were only for total rot damage. Rainfall data taken in a uniform manner are available for all the years involved, and for each of the four periods correlation coefficients were calculated between rainfall for certain months and rot development at the end of the season.

The rainfall during June and July was used in the correlation studies even though ears are not yet formed in these months. According to Burrill and Barrett (3), "the best spore-producing periods for *Diplodia zeae* seem to follow hot, rainy weather preceded by more or less continued dry spells." Ullstrup (57) says that *D. zeae* "is most

Table 2. — Correlation of Corn Ear Rot After Maturity With Rainfall at Urbana and in Illinois as a Whole

Years, location, and method of determining ear-rot prevalence	Months for which rainfall was used in calculations	Correlation coefficients between rainfall in specified months and ear rot caused by—				
		All causes	*Diplodia zeae*	*Fusarium moniliforme*	*Gibberella zeae*	*Nigrospora oryzae*
1924-1941, Urbana (Ear examinations[a])	June	−.204	.015	−.460	.171	.196
	July	−.499*	−.247	−.468*	−.002	−.213
	June and July	−.455	−.149	−.603**	.011	−.008
	Aug.	.329	.461	−.235	.464	.517*
	Sept.	.613**	.326	.401	.442	.484*
	Oct.	.198	.437	−.038	.067	−.275
	Aug. and Sept.	.709**	.539*	.208	.640**	.706**
	Aug., Sept., Oct.	.651**	.635**	.144	.533*	.418
1940-1951, Urbana (Kernel examinations[b])	Aug.	.320	.055	.643*	.250	.299
	Sept.	.651*	.702*	.467	−.183	.062
	Oct.	.470	.415	.639*	.227	−.034
	Aug. and Sept.	.635*	.549	.628*	.012	.222
	Aug., Sept., Oct.	.797**	.629*	.725**	.176	.105
1935-1952, state-wide (Kernel examinations[c])	Aug.	−.189	(Data not available)			
	Sept.	.489*				
	Oct.	.416				
	Aug. and Sept.	.301				
	Aug., Sept., Oct.	.509*				
1916-1941, state-wide (Carloads grading 5% damage in June[d])	Aug.	.312				
	Sept.	.666**				
	Oct.	.027				
	Aug. and Sept.	.689**				
	Aug., Sept., Oct.	.630**				

[a] For ear-rot prevalence, see Fig. 22.

[b] For ear-rot prevalence, see Fig. 23.

[c] See Illinois Agricultural Experiment Station Bulletins 427, 429, 440, 450, 463, 474, 482, 500, 509, 517, 521, 527, 531, 536, 544, 552, and 564 for annual data on rot prevalence in many hybrids used for this computation.

[d] For ear-rot prevalence, see Fig. 24.

* Significant at the 5-percent level. ** Significant at the 1-percent level.

prevalent in years when June and July are dry and August and September are wet." The data obtained here give some support to these conclusions, although they held more definitely for rot by *Fusarium moniliforme* than for *D. zeae.* The 1924-1941 period was the only one for which correlations between rot damage and June-July rainfall were significant at the 5-percent level. Therefore, the rainfall for June and July is given only for this period in Table 2. A dry July was of more significance than a dry June, although both seemed to have some influence on the prevalence of rot by *F. moniliforme.*

Correlations between ear-rot prevalence and rainfall in August, September, and October were primarily on the positive side and some of them were significant to the 1-percent level. In general, September rainfall had the most decisive influence on ear-rot development; and August and October were about equal in importance.

When *Diplodia zeae* alone was considered, a significant correlation was found between its occurrence and September rainfall, and also August and September rainfall combined; highest significance was in the correlation between prevalence and the 3-month average rainfall

(Table 2). The prevalence of *Fusarium moniliforme* was about equally affected by rainfall in each of the 3 months taken singly (in 1940-1951); and again the highest significance was found for the 3-month average.

Correlations between *Gibberella zeae* and August and September rainfall were substantial for the 1924-1941 period, but significance occurred only for the 2- and 3-month averages. Data on prevalence of Nigrospora ear rot for the same time period showed significant correlations with rainfall in August and in September and with the August-September average. This agrees with observations by Durrell (9). In both time periods studied, high rainfall in October definitely did not aggravate rot caused by Nigrospora.

Rainfall in November can also be of importance when the grain moisture is above 21 percent, but this month was not included in the correlations because the average harvest date for these experiments was about November 15. That ear rots may continue to increase in November of some years is shown in Table 6.

Inherited Resistance

No known corn inbreds or hybrids are immune or very highly resistant to the various ear-rot diseases, but some that are superior in resistance have been reported (20, 26, 28, 30, 45, 46, 56, 67). Data involving a few specific resistant single and double crosses are shown in Tables 4, 5, 11, 12, 13, and 15. Inbreds Ill. 90, Ill. R4, CI.540, Ia. 701, Ia. B10,[a] and Ill. R59[a] appear to be among the best available of the corn belt lines for transmitting combined resistance to ear rots caused by *Diplodia zeae* and *Fusarium moniliforme*. These inbreds, however, are not used to any extent commercially. Ill. 90, which also has outstanding resistance to some seedling blight diseases, unfortunately lacks yield factors. Ill. R59 has a cob that dries slowly, often resulting in cob rot. The other inbreds mentioned are very susceptible to some of the stalk-rot diseases or have other serious faults. Among the inbreds in wide use, however, some transmit significantly better resistance to crosses than others, and differences between hybrids do exist.[b]

Inherited resistance to any one rot is largely independent of inherited resistance to other rots. Wiser (67), in discussing the mechanisms

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[a] Rating based on tests at only one location. The others have been tested more thoroughly.

[b] For reference see Table 2, footnote (c), with emphasis on the 3-year averages when given.

of the inheritance of resistance to Diplodia ear rot, points out that resistance to Diplodia is multigenic. This is also true of other commonly occurring ear rots.

On the whole, not much advance in genetic control of ear rots has as yet been made in hybrids widely grown in Illinois. The general advance in ear-rot control through use of hybrids appears to result from the tendency of hybrids to stand more erect and mature more uniformly than the open-pollinated varieties.

Inherited resistance will be discussed further under the headings: "Aids in Breeding for Ear-Rot Resistance" (page 76), and "Control Measures" (page 79).

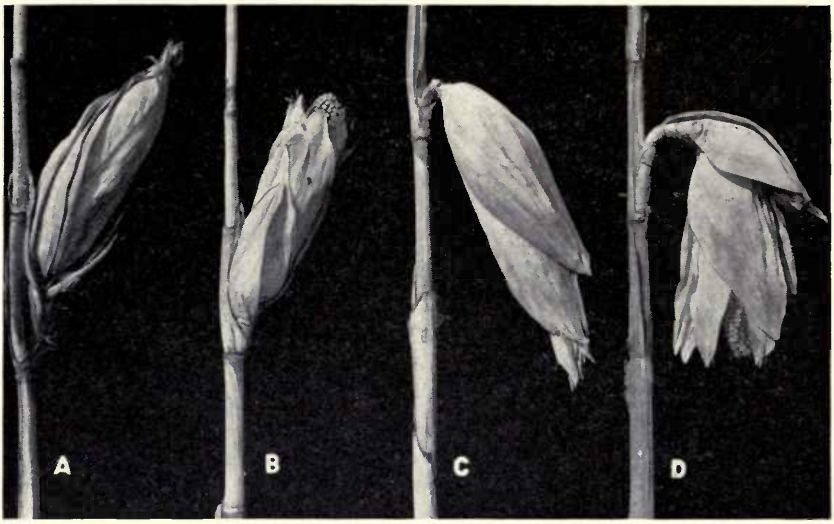
Ear Declination

Working in Texas, Taubenhaus (53) concluded that to control the yellow Aspergillus molds attacking corn ears, it is only necessary to select pendant ear types. Koehler and Holbert (30) reported that erect

Table 3. — Ear Declination, Contact With Ground, Husk Coverage, and Presence of Corn Ear Worms in Relation to Percentage of Rot-damaged Corn Kernels; Open-pollinated Station Strain of Reid Yellow Dent, Urbana, 1943-1945

Ear classification	Prevalence of rot-damaged kernels caused by:				
	Dip. zeae	*Fus. monil.*	*Gib. zeae*	*Nigr. oryzae*	All causes
			percent		
Erect[a]	.75	1.21	.25	.08	2.85
Declined[a]	.46	.55	.13	.09	1.44
Tips touching ground	.68	.72	.19	.25	2.18
Ears flat on ground	1.11	1.96	1.08	1.83	6.89
L.S.D., 5-percent level	N.S.[b]	.63	.51	.72	1.15
Erect					
Covered by husks	.49	.89	.27	.08	2.20
Husks open	.72	1.50	.25	.11	3.09
Declined					
Covered by husks	.45	.44	.08	.10	1.38
Husks open	.59	.77	.18	.13	1.95
Erect					
Free from ear worms	.59	.76	.34	.07	2.13
Ear worms present	.62	1.63	.18	.13	3.16
Declined					
Free from ear worms	.32	.37	.06	.09	1.00
Ear worms present	.72	.83	.19	.14	2.34
L.S.D., 5-percent level	N.S.[b]	.45	N.S.[b]	.05	.56

[a] See Figure 25. [b] N.S. means not significant.



Differences in husk coverage and ear declinations: (A) erect and covered, (B) erect and exposed, (C) declined and covered, (D) declined and exposed. Ear rot prevalence in ascending order was: C, D, A, B. (Fig. 25)

ears are more subject to seed infection than those in a declined position. Results from a more recent 3-year experiment on the effect of ear position on ear-rot prevalence are reported here.

To be assured of ears in various positions, including ears touching the ground, and also to be sure that ear position would be genetically independent of variations in ear-rot resistance, an open-pollinated variety of Reid Yellow Dent was used. Seven adjacent plots, each 10 by 40 hills, were planted in each of two fields in 1943, 1944, and 1945. Ears were harvested in November each year and immediately separated into four classifications on the basis of ear position (Table 3). On one field each year, ears classified as erect or declined were further subdivided according to degree of husk coverage at harvest (Fig. 25). Further classification was later made on the basis of worm injuries. Only ears that were good representations of these classes were taken; those that were borderline in ear declination or husk coverage or that were declined because of broken shanks were discarded. While the classifications show the ear positions at harvest, the length of time the ears had been in these positions (except for erect ears) is not known.

Erect ears had a significantly higher percentage of Fusarium rot, and of all rots combined, than did the declined ears. There was also a numerical difference in the same direction for Diplodia and Gibberella rots, but the differences were not significant.

From these and other results (28, 67) it was concluded that of the three characters influencing ear-rot prevalence — inherent resistance, husk coverage, and ear declination — declination ranked third in importance.

Husk Protection

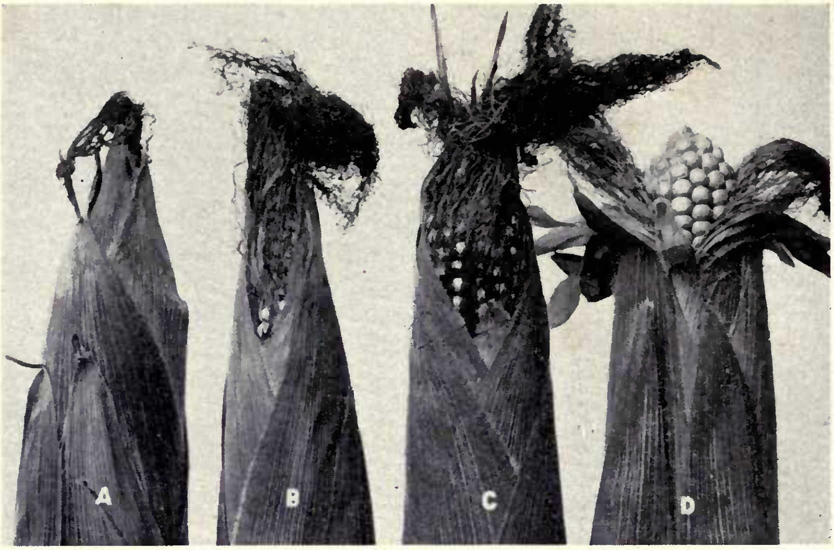
As early as 1918, Kyle (31) published some data showing that rotten and discolored ears were very much more abundant when husk protection was poor than when it was good. Holbert et al. (15), studying factors affecting seed quality, found that seed infection with *Fusarium* species and *Diplodia zeae* was much more common when the ear tips had not been covered by the husks. Koehler (26, 27, 28) and Wiser (67) reported the same for certain ear rots.

Boewe (1), when considering all corn ears having any rot-damaged kernels, found rot to be most prevalent in ears poorly covered by husks. This relationship was especially strong for infections by *Fusarium* and *Penicillium* species. He found, however, that rots caused by *Diplodia zeae* and *Gibberella zeae* were somewhat more prevalent in well-covered ears. Some of the infections with *D. zeae* and *G. zeae* may occur early, before much tip exposure has taken place. Early infected ears become severely rotted, and the fungus mycelium binds the husks tightly to the ears so that they cannot open. This gives a bias that under some conditions may correlate rotted ears with closed husks.

Ear rot when husks opened naturally. In the experiment on ear declination discussed in the preceding section, the classification "covered by husks" and "husks open" were also included (Table 3, Fig. 25). For nearly all rot classes given in Table 3, the 3-year averages show a higher incidence of rot when the husks were open. Significant differences, however, occurred only for total rot and Fusarium rot damage, and only in ears in the erect class. When ears are declined (Fig. 25), rain water drains away more easily and so it is not surprising that in this class open husks were less detrimental.

Johnson and Christensen (22) observed that corn-smut infection tended to increase the development of corn ear-rot diseases, particularly when the smut occurred on the ears. Smut galls on the ears are great enlargements of the kernel tissues which spread, loosen, and open up the husks. The decrease in husk protection may be an important cause of the increased ear rot.

Husks opened by hand. Another kind of experiment on the value of husk protection against ear-rot infection was conducted for a 3-year period using hybrids. Husks were opened by hand (Fig. 26) at various



Tips of four corn ears about 30 days after pollinating: (A) ear covered by husks, (B, C) husks opened naturally, (D) husks opened by hand to accelerate ear rot development. (Fig. 26)

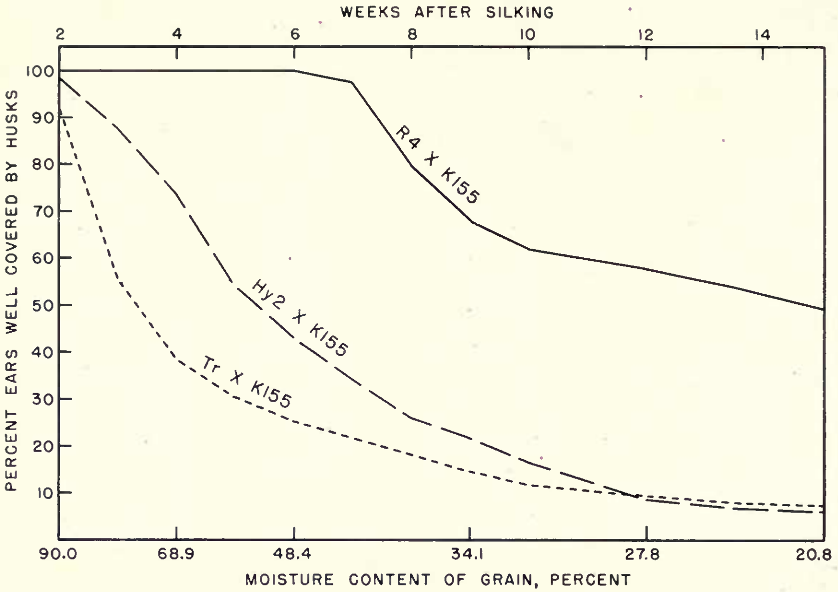
dates representing different stages of development of the ears (Table 4). At the times the husks were opened any ears with husks already open and any ears observed to be already rot-damaged were removed. The "not opened" class contained only ears that were covered by the husks at harvest time.

The earlier the husks were opened, the greater the amount of rot. The differences were significant for all rot categories in the summary for all hybrids (Table 4). Even on ears with husks opened as late as September 19, there was a significant increase in total rots and rot by *Fusarium moniliforme*. Some of the hybrids had more resistance to rots than others. Big increases in rot occurred in all of them when the husks were opened early, but the resistant cross CI.504 × Ill. R4 retained its superiority when comparisons were made for the same husk-opening dates.

Husk protection in three hybrids. In Fig. 27, we see, for three hybrids, the changes that took place over a period of time in degree of husk protection. Inbreds R4, Hy2, and Tr, rating good, medium, and poor respectively in husk coverage, as previously determined in crosses, had each been crossed with inbred K155, which rated good in husk coverage. These were planted in test plots and data were taken at

Table 4. — Corn Ear-Rot Prevalence in Relation to Ear-Tip Exposures Artificially Made by Opening Husks at Various Stages of Ear Development, Urbana, 1942-1944

Hybrid, year, and approximate dates husks were opened	Grain moisture content when opened	Prevalence of rot-damaged kernels caused by:				
		Dip. zeae	*Fus. monil.*	*Gib. zeae*	*Nigr. oryzae*	All causes
				percent		
U. S. 13 (Av., 1942 and 1943)						
Aug. 20	72	13.4	2.5	...	...	17.4
Aug. 30	54	10.1	.9	...	...	12.6
Sept. 9	44	7.1	.7	...	...	8.6
Sept. 19	38	2.5	.6	...	...	3.7
Not opened	..	1.7	.4	...	...	2.9
L.S.D., 5-percent level	..	3.1	N.S.	...	...	1.7
Ill. 960 (1944)						
Aug. 20	71	3.9	2.0	.20	.55	7.8
Aug. 30	54	2.7	1.8	.11	.16	5.4
Sept. 9	40	1.6	1.3	.00	.15	3.6
Sept. 19	34	2.1	.7	.09	.11	3.2
Not opened	..	1.6	.9	.00	.13	2.8
Ill. 201 (1944)						
Aug. 20	71	4.8	2.8	.15	.12	10.0
Aug. 30	50	2.7	2.5	.14	.15	6.9
Sept. 9	39	1.3	2.0	.15	.06	5.0
Sept. 19	30	1.9	2.2	.09	.05	5.4
Not opened	..	2.5	1.2	.05	.03	4.8
CI. 540 × Ill. R4 (1944)						
Aug. 20	68	2.9	1.1	.10	.19	5.2
Aug. 30	53	1.7	.9	.04	.10	3.2
Sept. 9	39	1.3	.7	.05	.04	2.8
Sept. 19	29	.8	.4	.00	.03	1.8
Not opened	..	.6	.3	.01	.02	1.5
Ind. Tr. × Ill. Hy2 (1944)						
Aug. 20	68	11.4	3.9	.25	.26	17.1
Aug. 30	53	6.3	2.8	.08	.32	10.7
Sept. 9	41	2.9	2.6	.03	.03	7.0
Sept. 19	32	2.0	3.5	.03	.19	6.2
Not opened	..	2.4	1.6	.01	.09	4.6
			Summary			
All dates (1944)						
Ill. 960	..	2.37	1.29	.08	.22	4.54
Ill. 201	..	2.66	2.15	.12	.08	6.39
CI. 540 × Ill. R4	..	1.44	.67	.04	.08	2.91
Ind. Tr × Ill. Hy2	..	4.98	2.87	.08	.18	9.10
L.S.D., 5-percent level	..	2.18	.48	N.S.	N.S.	.78
All hybrids (1944)						
Aug. 20	69.5	5.77	2.46	.18	.28	10.00
Aug. 30	52.5	3.34	1.96	.09	.18	6.52
Sept. 9	39.7	1.75	1.62	.06	.07	4.59
Sept. 19	31.2	1.68	1.68	.05	.10	4.16
Not opened	..	1.77	1.01	.02	.07	3.42
L.S.D., 5-percent level	..	2.40	.58	.07	.14	.41



Natural progress of husk opening in three hybrids. Ears were considered exposed when kernels or the tip of the cob could be seen. (Fig. 27)

frequent intervals from 2 weeks after silking until maturity. Even though Tr had been crossed with an inbred contributing good husk coverage, some ear tips were already exposed in mid-August, when the first observations were made. At 4 weeks after silking, when the corn was still in the milk stage, only 39 percent of the ears were covered. Coverage continued to decrease, although it had not reached zero at harvest time.

When two inbreds contributing good husk coverage were crossed (R4 X K155), no ears were exposed the first 6 weeks, and 50 percent were still well covered at harvest time (Fig. 27). Thus, all the ears were well covered during the time that usually is most critical for infection.

Lodging

Studies were made of rot in lodged corn to determine the relationships between rots and (a) the kind of contact of the ear with the soil and (b) the stage of ear development when lodging occurred.

Inspections were made in 1937 of two widely separated fields of hybrid corn in which much lodging occurred. The two hybrids were identified by different proprietary numbers. Arrangements were made with the farmers to collect ears from erect and lodged plants. When the collection was started it at once became evident that more than half the ears in contact with the ground were not lying flat, but were more or less in an upright or inclined position with only the tip end resting on the ground (Fig. 28). Therefore, the following three "position of ear" classes were collected, each class was shelled, and percent of rot-damaged kernels determined.

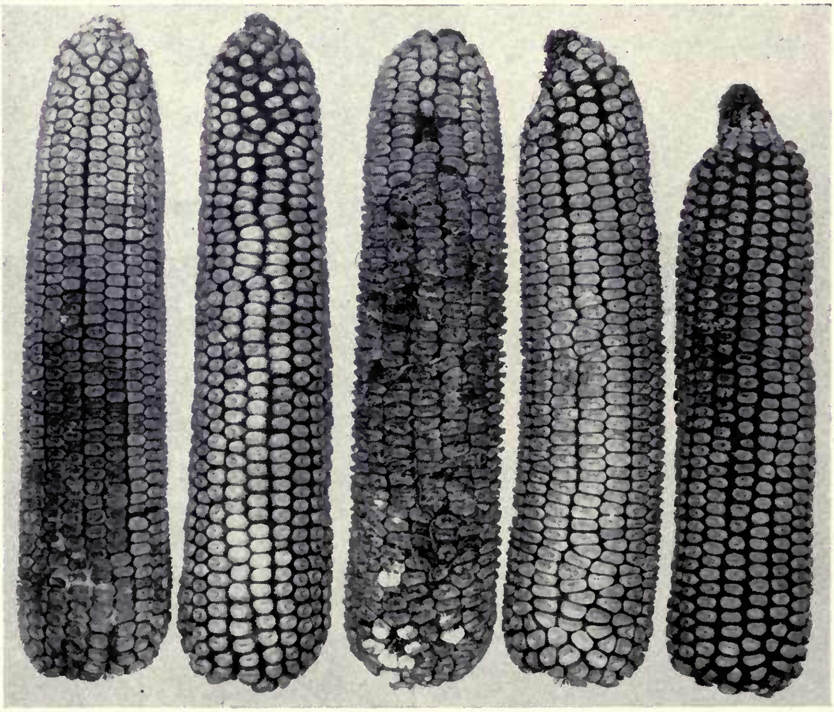
County	*Position of ear*	*Rot damage, pct.*
Cumberland	Erect	2.49
	Tip resting on ground	1.69
	Flat on ground	3.20
Mason	Erect	.61
	Tip resting on ground	.73
	Flat on ground	1.44

When only the tip end of an ear rested on the ground as at right, rot was no worse than the average for erect plants. But when the ear was flat on the ground, as shown below, ear rot damage was greatly increased. (Fig. 28)

Variations in rainfall partially account for some of the differences between the two locations in amount of rot. According to records at the nearest weather stations, the combined rainfall for August, September, and October at the Cumberland county location was about twice as great as in Mason county. Furthermore, the subsoil drainage at the former location obviously was not as good as in the sandy loam at the latter place.

It was surprising that ears with tip ends resting on the ground had scarcely any more rot than the erect ears in Mason county and actually had less rot damage than the erect ears in Cumberland county. More extensive data obtained later in a 3-year test at Urbana verified these results (Table 3).

According to the tests reported in Table 3, Nigrospora, Fusarium, and Gibberella ear rots, as well as total rots, all increased significantly



Ears that had been flat on the ground as in Fig. 28, bottom. The cause of rot is harder to identify by symptoms in such ears than in ears on standing stalks. The principal fungi in the ears shown here are (left to right): *Diplodia zeae*, *Fusarium moniliforme*, *Nigrospora oryzae* (many kernels had also germinated), *Trichoderma viride* (Pers. ex Fries) Bisby, and *Alternaria* sp. (Fig. 29)

Table 5. — Corn Ear-Rot Prevalence in Relation to Natural Lodging, and to Lodging Artificially Induced at Different Dates, Urbana, 3-Year Average, 1935, 1937, and 1938

Variety and lodging condition	Moisture of grain		Test weight per bu.	Rot-damaged ears caused by:						Rot-damaged kernels
	When lodged	When harvested		*Dip. zeae*	*Fus. monil.*	*Gib. zeae*	*Nigr. oryzae*	Misc. and unidentified	Total	
Hybrid A	*perct.*		*lb.*				*percent*			
Standing stalks only	....	17.7	58.1	0.7	1.1	.1	.1	0	2.0	1.3
Naturally lodged	....	19.8	57.0**	1.1*	1.9**	.2	.5	.2	3.9**	2.3*
Lodged Oct. 1-5	28.8	21.3	57.0**	1.0*	1.8**	.1	.4	.6	3.8**	2.5**
Lodged Sept. 16-20	38.0	22.7	56.6**	2.1**	3.0**	.1	.9	.9	6.9**	3.5**
Lodged Sept. 3-7	50.4	23.3	55.1**	4.0**	4.1**	.1	1.9	.9	11.0**	4.8**
Hybrid B										
Standing stalks only	....	18.8	56.4	1.0	6.7	0	.2	0	7.9	2.8
Naturally lodged	....	21.7	55.8*	1.2	9.4*	.1	1.6	.3	12.6**	4.0*
Lodged Oct. 1-5	31.6	24.5	55.3**	1.7	10.0**	0	1.4	1.1	14.2**	5.7**
Lodged Sept. 16-20	39.7	25.2	54.8**	2.7*	11.2**	.1	2.9*	2.9*	19.8**	6.5**
Lodged Sept. 3-7	54.7	26.3	53.1**	5.5**	15.0**	0	8.0**	5.1**	33.7**	12.2**
Open-pollinated A										
Standing stalks only	....	18.9	58.5	1.5	1.4	.2	0	0	3.1	1.9
Naturally lodged	....	20.2	57.5**	1.7	1.8	.4	.7	.1	4.7	2.3
Lodged Oct. 1-5	31.1	22.8	57.4**	2.8	3.1	0	.3	.7	6.9*	3.7**
Lodged Sept. 16-20	38.7	23.2	57.1**	3.3**	4.0*	.2	1.4	1.7	10.6**	5.1**
Lodged Sept. 3-7	51.7	23.9	55.6**	5.9**	6.0**	.3	3.3*	3.2*	18.7**	8.8**
Open-pollinated B										
Standing stalks only	....	20.1	55.4	1.2	4.3	.1	.2	0	5.7	1.8
Naturally lodged	....	22.1	53.7**	1.8	3.9	0	1.1	.5	7.3	4.5*
Lodged Oct. 1-5	33.3	24.9	53.7**	1.6	7.1*	.2	.8	1.6	11.4**	5.5**
Lodged Sept. 16-20	45.4	25.3	53.2**	2.2**	7.2*	0	2.4	3.1*	14.8**	6.9**
Lodged Sept. 3-7	57.0	26.9	51.1**	3.8**	9.1**	.2	4.5*	4.7*	22.3**	10.2**

* Indicates significance at the 5-percent level for decrease in test weight or increase in rot prevalence as compared with figures for corn from standing stalks, based on conversion of percentages to angles.

** Indicates significance at the 1-percent level, for same comparisons as above.

when ears were flat on the ground. That the greatest increase occurred in Nigrospora rot confirms the findings of Standen (49), who reported lodging as one of the factors that increase the incidence of this rot. *Alternaria* spp. occurred frequently, primarily on ears flat on the ground, and *Trichoderma* spp. occurred only on such ears (Fig. 29).

To obtain information on the relationship between ear-rot development and time of lodging, two hybrids in commercial use and two open-pollinated varieties were lodged artificially at approximately 2-week intervals (Table 5). To accomplish lodging, the roots in a hill were first cut off with a spade, about 6 inches from one side of the stalk bases. The plants were then pried and pushed until they were in a horizontal position (Fig. 30). Actually, the artificially lodged plants remained

A corn hill that lodged naturally after corn root worm attack (top) and a hill that was lodged manually to obtain data shown in Table 5. The two kinds of lodging were very similar. (Fig. 30) better fastened to the soil than plants that became naturally lodged following corn root worm injury. All plants already naturally lodged at the time of each artificial lodging were removed. The experiment was conducted for 4 years but was not carried to completion in 1936 because of a severe drouth.

The two hybrids differed greatly in susceptibility to ear rots, especially Fusarium, Nigrospora, miscellaneous, and total rots (Table 5). The two open-pollinated varieties ranked between the hybrids, and they also differed with respect to Fusarium and total rots. The four varieties differed only slightly in resistance to Diplodia ear rot. This was a coincidence, as hybrids may differ greatly in this respect (28, 56) (Tables 4, 11, 12).

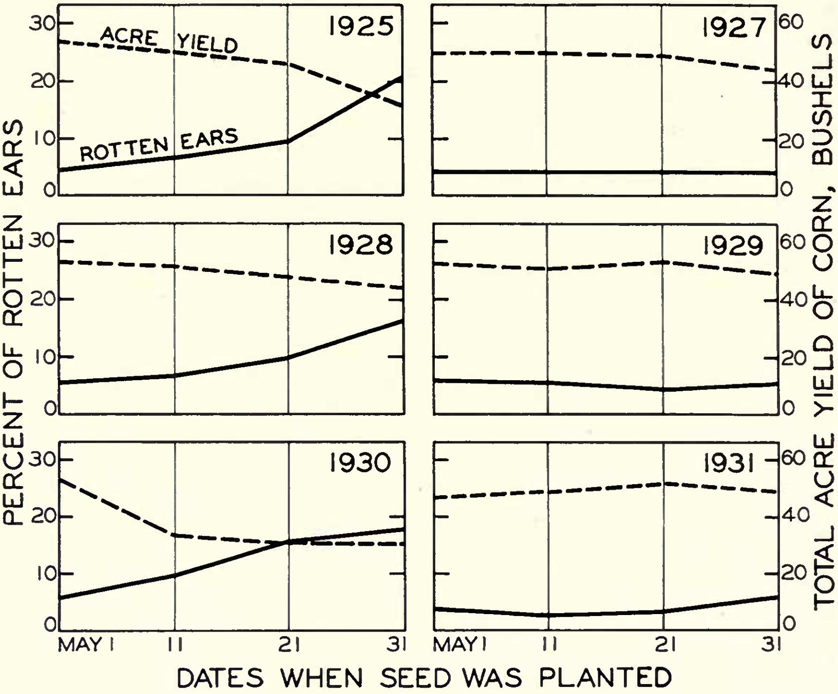
The naturally lodged plants indicated in the table were primarily the result of stalk breaking. They were considered lodged when the ear was in contact with the ground at harvest time. Most of the ears were touching the ground only with their tips (Fig. 28) and this accounts for the comparatively low amount of rot in this classification. It has been observed, on the other hand, that when plants are lodged because of root failure, a higher proportion of the ears are flat on the ground. One fact that shows clearly in the data is that regardless of variety or hybrid, the earlier the lodging occurred, the greater the amount of rot. Furthermore, those kinds of corn that had the most Fusarium rot or "total rot" when standing also had the most when lodged.

One nonconformity between results in Tables 3 and 5 is with respect to *Gibberella zeae*. In the one case, ears flat on the ground had a significantly higher percentage of rot, while in the other lodging had no effect. This may have occurred because these two experiments were performed in different years under different environmental conditions. For the other pathogens, there is good agreement.

When judged by ear symptoms (Fig. 29), the cause of rot damage is more difficult to determine in lodged corn than in standing corn. The most satisfactory method found was to separate the kernels showing rot damage and then to identify the fungi by laboratory methods.

Time of Planting

A 6-year time-of-planting experiment was conducted with the station strain of Reid Yellow Dent corn. The data presented in Fig. 31 are based on an annual average from five fields representing several crop rotation systems, and several sequences in the rotation. The times of planting, from May 1 to May 31, were within the range for good corn production practice.



Influence of time of planting on corn ear-rot prevalence and acre yield. Delayed planting increased ear rots three years out of six. (Fig. 31)

In 3 of the years, the percentage of ear-rot damage increased with delay in planting, while in the other 3 years rot damage, as well as acre yield, was nearly constant for the four planting dates. In no case during the 6 years did early planting increase ear rot in this corn variety.

Time of Harvesting

Corn ears were harvested on approximately October 1, November 1, and December 1 during 11 years. In 9 of those years the difference in rot damage between the first and last date was outstanding (Table 6). In 4 years there appeared to be a substantial difference between the November 1 and December 1 harvestings, and in 1 of those years the difference was very large. There were no appreciable increases in rot after the average grain moistures were 21 percent or lower.

For any one date of harvesting throughout the 11 years, no correlation existed between the moisture content of the grain and amount of kernel rot when harvested. As stated earlier in this bulletin, there was a correlation between rainfall and ear-rot prevalence, but apparently

Table 6. — Amount of Rot-Damaged Kernels When Corn Was Harvested at Different Times, Urbana, 1936-1947

Kind of corn and year	Grain moisture			Rot-damaged kernels		
	Oct. 1	Nov. 1	Dec. 1	Oct. 1	Nov. 1	Dec. 1
Open-pollinated			*percent*			
1936	24.6	19.6	16.6	3.1	5.8	5.9
1937	24.5	21.7	16.7	1.1	2.1	2.3
1938	22.0	15.8	13.4	1.8	3.3	3.1
Hybrids						
1940	27.1	23.1	19.2	1.1	2.6	2.6
1941	29.8	25.7	21.6	3.1	5.8	8.2
1942	26.3	21.1	17.5	2.8	4.2	4.6
1943	36.8	24.7	21.2	1.2	2.0	2.1
1944	45.2	29.4	23.9	2.0	2.4	3.6
1945	43.8	29.0	25.9	1.0	1.6	3.0
1946[a]	39.5	28.1	24.6	.2	.5	.9
1947	40.9	30.0	27.8	.8	1.9	6.8
Average	32.8	24.4	20.8	1.7	2.9	3.9

[a] A year of exceptionally low ear-rot prevalence (*see* Fig. 23).

there was little relationship between rainfall and degree of maturity. The stage of maturity at these dates, as measured by grain moisture, was no doubt largely influenced by the time of planting and the temperature during the growing season. Beginning about 1940, the time of planting was changed to a later date (approximately May 20) according to recommendations for corn borer control.

Cropping Sequence

The effects of cropping system on rot damage were studied during two 4-year periods on three long-time rotation systems at Urbana. Crop rotations and soil treatments had been handled uniformly since 1903.

Results of the more recent study (1940-1943) are given in Table 7. The more frequently corn appeared in the rotation, the lower the yield and the higher the damage from Diplodia ear rot and from total rots. Yield decreased and the damage from Diplodia and total rots increased with each consecutive year corn was in the rotation. There was no similar significant effect, however, on ear rots caused by *Fusarium moniliforme* or *Gibberella zeae*. This experiment was made with hybrid U. S. 13, and the data are based on kernel separations in shelled corn, followed by plating of rot-damaged kernels.

A somewhat similar experiment was made in the same rotation systems in 1928-1931. At that time the station strain of Reid Yellow Dent corn was used, and the rot determinations were made by the ear examination method. Results were similar to those in 1940-1943.

Diplodia rot increased with increasing intensity or continuity of cropping with corn, but no similar trends were apparent for rots caused by *Fusarium moniliforme* and *Nigrospora oryzae.*

These data tend to support the statement by Burrill and Barrett (3) that ". . . as a rule ear rot is more prevalent and destructive in fields planted successively to corn than in those on which a good system of rotation is practiced."

Table 7. — Effect of Crop Rotation, Cropping Sequence, and Soil Fertility on the Prevalence of Rot-Damaged Corn Kernels; Hybrid U. S. 13, Urbana, 1940-1943

Rotation	Place of corn in rotation	Basic soil treatment	Mineral fertilizer added	Acre yield, 4-yr. aver.	Prevalence of rot-damaged kernels caused by:			
					Dip. zeae	*Fus. monil.*	*Gib. zeae*	All causes
A				*bu.*	*pct.*	*pct.*	*pct.*	*pct.*
Corn	1 yr.	Residues	None	79.8	1.24	1.59	.18	4.44
Oats			Phosphate	86.6	1.50	1.08	.11	3.43
Wheat		Manure	None	102.7	1.73	1.47	.06	4.37
Clover			Phosphate	106.8	1.78	1.40	.12	4.34
B	1st yr.	Residues	None	83.4	1.79	1.28	.07	3.69
Corn			Phosphate	95.0	1.71	1.01	.08	3.30
Corn		Manure	None	91.9	1.84	1.23	.15	4.21
Spring grains			Phosphate	96.0	1.66	1.33	.08	4.39
Clover	2nd yr.	Residues	None	69.5	3.70	1.36	.12	5.82
			Phosphate	75.5	3.02	1.21	.30	5.41
		Manure	None	85.8	4.16	2.05	.11	7.08
			Phosphate	88.7	2.69	1.62	.06	5.15
C	1st yr.	Residues	None	64.2	2.44	1.30	.07	4.82
Corn			Phosphate	68.2	1.85	1.16	.08	4.20
Corn		Manure	None	80.5	1.83	1.02	.03	3.84
Corn			Phosphate	82.0	1.19	1.01	.04	3.05
Soybeans								
	2nd yr.	Residues	None	54.8	3.48	1.48	.08	6.18
			Phosphate	58.0	3.04	1.12	.12	5.17
		Manure	None	67.9	2.62	1.54	.08	5.41
			Phosphate	67.4	1.78	.94	.07	3.66
	3rd yr.	Residues	None	53.8	2.79	1.04	.04	4.58
			Phosphate	55.7	4.00	0.99	.10	5.95
		Manure	None	64.0	1.87	1.28	.10	4.27
			Phosphate	62.2	3.83	1.13	.10	5.79
		L.S.D., 5-percent level		4.7	1.25	.53	N.S.[a]	1.33
		Summary						
A	1 yr.	All soil treatments		94.0	1.56	1.39	.12	4.14
B	1st yr.	All soil treatments		91.6	1.75	1.21	.10	3.90
	2nd yr.	All soil treatments		79.9	3.39	1.56	.15	5.80
C	1st yr.	All soil treatments		73.7	1.82	1.12	.06	3.98
	2nd yr.	All soil treatments		62.0	2.73	1.27	.09	5.11
	3rd yr.	All soil treatments		58.9	3.12	1.11	.08	5.15
		L.S.D., 5-percent level		5.7	1.15	N.S.	N.S.	1.49
All	All	R+M[b]	None	74.9	2.46	1.39	.09	4.89
All	All	R+M	Phosphate	78.5	2.34	1.17	.11	4.49
		L.S.D., 5-percent level		3.2	N.S.	.15	N.S.	.38

[a] N.S. means not significant.
[b] Residue and manure treatments combined.

Soil Fertility

Along with the studies of rot prevalence in three cropping systems, studies were conducted on the effects of different soil treatments. In the grain systems, the straw and fodder produced on the plots were plowed under, as well as the second clover crop. In the livestock system manure was applied to equal the straw and fodder removed. Also, since the establishment of the plots, part of the soil in each cropping system had received several additions of rock phosphate. Up to 1940 a total of 6½ tons per acre had been applied. Untreated plots all tested "low" in phosphorus.

Corn yields were considerably higher on plots receiving manure than on the residue-treated plots, but there were no significant differences in ear-rot development. Phosphate treatment decreased Fusarium ear rot and total ear rot significantly (Table 7, summary), but it had no significant effect on ear rots caused by *Diplodia zeae* or *Gibberella zeae.* Similar effects of phosphorus on ear rots had been observed in the same rotations during the 1928-1931 period, when open-pollinated corn was used.

From these results with two kinds of corn in two different time periods, as well as from other observations (3), the generalization can probably be made that, where phosphorus is low, the addition of phosphate fertilizer will somewhat lessen the ear-rot hazard. It must be remembered, however, that hybrids differ in susceptibility to ear rots and in their response to soil fertility variations.

Comparatively little is known about the effect of potassium, nitrogen, and other fertilizer elements on the development of corn ear rots. It was reported in 1909 (3) and observed at various times since then that ear rots at times are most severe on very fertile soils high in organic matter.

Physical Damage by Predators

It is well known that corn ear rots are aggravated by the feeding of corn ear worms, *Heliothis zeae* (Boddie) but little has been reported on the kinds of rots involved. Taubenhaus (53) found that in Texas the black ear mold, *Aspergillus niger,* occurred primarily on corn ears after they had been injured by corn ear worms. It was reported in 1930 that in Illinois ear rot caused by *Fusarium moniliforme* is very prone to follow corn ear worm injury (30). Somewhat later, data were presented on infections in corn kernels taken from sound ears and from ears injured at the tip end by worms (25). The kernels selected for test from the worm-injured ears were located some distance away from the injury and were sound in appearance. In this experiment *F. moniliforme* was by far the most prevalent fungus in kernels from worm-injured ears. Next in order was infection by *Gibberella zeae*. Prevalence of *Diplodia zeae, Nigrospora oryzae* and *Cephalosporium acremonium* was not affected significantly by worm injury.

Rot damage following corn ear worm feeding is presented in Table 3. Regardless of whether the ears were in an erect or declined position, rot caused by *Fusarium moniliforme* was increased significantly when ears had been attacked by corn ear worms. Nigrospora rot was increased a small but significant amount in worm-infested ears, and increases in total rot were highly significant. Rots by *Diplodia zeae* and *Gibberella zeae* were not increased significantly in this experiment.

Penicillium molds, included with other miscellaneous fungus infections under "all causes" in Table 3, were particularly prevalent in 1944, and were present primarily on the tips of the ears that had been injured by ear worms.

The most constant association observed in Illinois between corn ear worm damage and fungus infections of the kernels, is infection with *Fusarium moniliforme.*

Physical injuries on immature corn ears by other predators may also aid in the development of rots. Whitney (66) recorded extensive ear-rot data on ears attacked by birds, primarily redwing blackbirds and starlings. Greatest increase in rot following bird damage was caused by *Fusarium moniliforme* (*Gibberella fujikuroi*), followed by *Diplodia zeae, Gibberella zeae,* and *Penicillium* species in decreasing order.

The European corn borer, *Pyrausta nubilalis* (Hbn.), feeding on corn shanks, causes them to weaken from physical injuries and from rots that may follow. A frequent result is that ears drop to the ground, where contact with the soil often increases ear-rot damage. According to Christensen and Schneider (4), European corn borers also provide the fungi with avenues of entrance directly to the ear and thus may be responsible for an increase in molds and ear rots.

INDUCED EPIDEMICS

Previous experiments to induce corn ear rot by inoculations have mostly been with *Diplodia zeae* (3, 5, 14, 39, 56, 64, 65, 67). The most extensive of these tests were by Ullstrup (56) and Wiser (67). Results from inoculation tests with some other ear-rotting fungi considered in this bulletin have also been published (10, 11, 23, 32, 40).

Objectives

The ear-inoculation tests reported here involved five fungi: *Diplodia zeae, Fusarium moniliforme, Gibberella zeae, Physalospora zeae,* and *Nigrospora oryzae.* Objectives were: (a) to determine the extent of rot development from inoculations made at various times, from a few days after silking until maturity; (b) to compare extent of rot when inoculum was applied by various methods and (c) at various locations on or near the ears; (d) to test these techniques as a means for providing better differentiation between resistant and susceptible corn inbreds or hybrids; (e) to determine loss in weight of kernels when the time of infection as judged by time of inoculation is known; and (f) to obtain some information on the length of time that cultures remain virulent and on the keeping quality of spore suspensions.

Methods of Inoculating

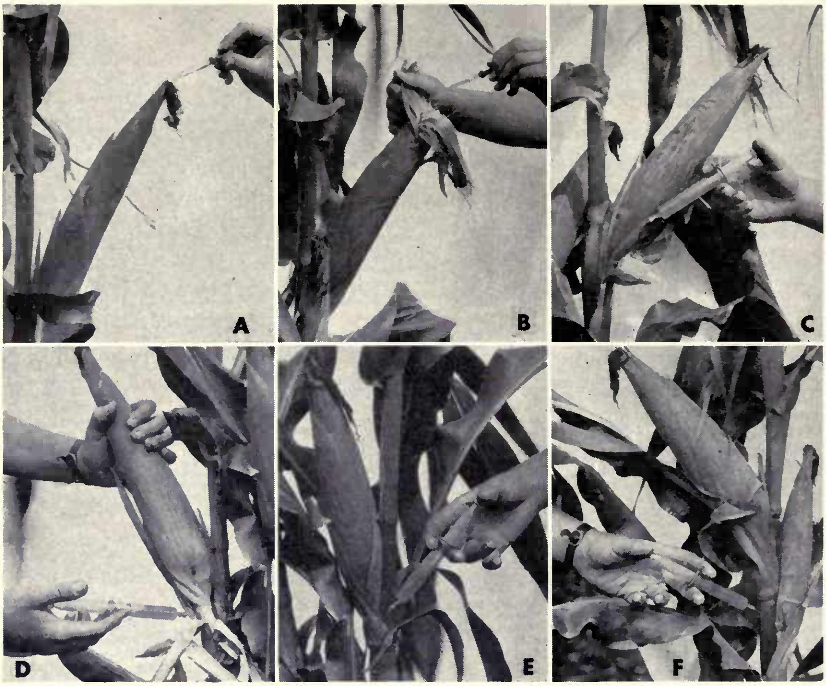
Silk inoculations. In most of the tests about ⅓ milliliter of spore suspension was applied to the silks at the place where they emerge from the husks (Fig. 32A), but without disturbing the husks. When the ear tip was exposed from natural causes (Fig. 26) the suspension was placed among the silks, and on the cob or kernels at the ear tip.

In some other experiments the spore suspension was applied to the silks and surrounding husks with an ordinary hand sprayer operated with compressed air supplied by a built-in hand pump. A diaphragm with a slightly smaller hole than original equipment was put into the spray nozzle, and the nozzle was attached to the rod in such a manner that when the rod was held at a 45-degree angle, the nozzle pointed straight down (Fig. 33). A shot lasting about 1 second was directed over the tip end of each ear.

The days after silking were counted from the time when nearly all primary ears were in full silk.

Tip-of-ear inoculations. Husks were opened enough that the spore suspension could be placed directly on the ear tip with a medicine dropper, using about ⅓ milliliter (Fig. 32B). When the ear tip was exposed naturally, one husk was raised slightly so that some suspension entered between the kernels and the husk. Some inoculations were made with the fungus culture growing on an oat kernel. In this case the oat kernel was inserted between the ear and a husk near the tip of the ear.

Husk inoculations. The lower half of an outer husk was punctured with the needle of a hypodermic syringe and a small amount of spore



Methods of inoculating ears with spore suspensions: (A) placed on silks, (B) placed on tip of ear, (C) inserted beneath outer husks, (D) injected into shank, (E) placed in axil of leaf subtending shank, (F) injected into stalk about 1 inch below the shank-bearing node. (Fig. 32)

Inoculating corn ears by the spray method. An ordinary compressed air sprayer was used, but the regular disk in the nozzle was replaced with one that had a slightly smaller hole, and a 90-degree elbow was added to bring the nozzle to a downward angle. Each ear was sprayed for about 1 second. (Fig. 33) suspension was inserted under it (Fig. 32C). After the husks became looser, some spore suspension was simply squirted between the husks.

Shank inoculations. A hole was punched in the shank and a small amount of spore suspension introduced with a hypodermic syringe (Fig. 32D). To avoid plugging of the needle by plant tissue a lacrymal point was used. This has a blunt end and slides into the opening without cutting plant tissue. Later an all-metal no-clogging type of inoculator was used that made its own hole (26).

Leaf inoculations. Spore suspension was dropped into the axil of the leaf at the node that bears the shank (Fig. 32E).

Stalk inoculations. The stalk was inoculated about an inch below the node that bears the shank, using the same methods as for shank inoculations (Fig. 32F).

Checks. Ears to serve as checks were inoculated with sterile water by the same methods as those treated with inoculums, except in hybrids where measurements for differences in resistance were sought. In that case the checks were left undisturbed.

Diplodia Zeae Inoculations

Preparation of inoculum. A strain of *Diplodia zeae* was selected for its ability to sporulate abundantly on autoclaved oats. The oats were boiled for 10 to 15 minutes in a volume of water 4 or 5 times the volume of the oats. They were left to soak about 24 hours and then drained on wire screen for a few seconds. Next, 1-quart milk bottles were half-filled with the drained oats. The bottles were closed with plugs of non-absorbent cotton and autoclaved for 1 hour at 15 pounds pressure. After cooling, a small amount of *D. zeae* culture was added to each bottle, and the bottles were placed in a well-lighted area at room temperature, but not in the direct sun. After 5 days they were shaken to distribute the newly grown mycelium well through the mass, and in 6 weeks pycnidia and mature spores were numerous.

Spore suspensions were sometimes made by emptying the oat culture into a large mortar, covering it well with tap water, and then working it with a pestle. The water quickly became dark with spores and was decanted into another vessel. The process was repeated with fresh water as often as a good yield of spores was obtained. Another method sometimes used was to place part of the oat culture from a bottle into a Waring blender with adequate water and then operate the blender for ½ minute.

In either case the suspension was first filtered through a sieve of 14- or 16-mesh wire (window screen) and then through a piece of voile having 60 meshes to the inch. A spore suspension thus filtered passed through the nozzle of the sprayer or needle of the inoculator with no trouble. The culture from one milk bottle under proper conditions made 1 gallon of very dark suspension consisting of about 8 million spores per milliliter as determined with a haemacytometer. Cleanliness was exercised, but no attempt was made to keep the suspensions free from contaminations.

Longevity of cultures and spore suspensions. After it was learned that a year-old Diplodia culture on cooked oats, although rich in spores, was not pathogenic, an experiment was conducted to obtain data on the length of pathogenicity. Cultures and spore suspensions were therefore started at different times and were all used in ear inoculations on the same day.

Cultures kept at room temperatures for 50 days were much more effective than those 105 days old; and still more effective than 210-day-old cultures (Table 8). When spore suspensions were stored at a temperature of 45°, they kept well for 14 days (as indicated by percent of rot-damaged kernels), but deteriorated somewhat in 24 days. When

Table 8. — Influence of Age of Culture, Age of Spore Suspension, and Storage Temperatures on Effectiveness of *Diplodia zeae* Spore Suspensions Used for Inoculating Hybrid U. S. 13, Urbana, 1949

(Inoculations made on tips of ears September 1, after husks were opened slightly)

Age of culture before making suspension	Age of suspension	Storage temperature of suspension	Diplodia rot: Rot-damaged ears	Diplodia rot: Rot-damaged kernels
days	*days*	*deg. F*	*perct.*	*perct.*
210	0	Uncontrolled[a]	20.7	13.0
105	0	"	54.2	39.5
50	0	"	87.4	62.9
50	24	45	74.3	58.7
50	14	45	78.5	62.6
50	7	45	86.8	62.1
50	24	Uncontrolled[a]	21.0	12.1
50	14	"	73.0	49.2
50	7	"	82.5	60.4
50	0	"	87.6	62.7
Check, ears not inoculated	..	....	4.0	2.2
L.S.D. at 5-percent level	..	....	15.0	16.3

[a] Room temperature, 65°-85°F.

suspensions were stored at room temperatures, deterioration was evident after 7 days, becoming progressively worse with longer storage (Table 8).

Results from direct application of inoculum. A comprehensive Diplodia ear inoculation test was repeated for 4 years using hybrid U. S. 13. In comparison with other hybrids, U. S. 13 ranked intermediate in susceptibility to ear rots in general.

Results of this test are given as (a) completely rotted ears, (b) completely plus partially rotted ears, and (c) all Diplodia-infected ears,

Table 9. — Diplodia Ear Rot and Ear Infection Resulting From Pure Culture Inoculations Made With *Diplodia zeae* at Different Locations on the Plant and at Different Times; Hybrid U. S. 13, Urbana, 4-Year Average, 1939-1942

Place and time of inoculating (no. of days after silking)[b]	Ears in test		Diplodia-rotted ears				All Diplodia-infected ears[a]	
			Completely rotted		Completely and partially rotted			
	Check	Inoc.	Check[c]	Inoc.	Check[c]	Inoc.	Check[c]	Inoc.
	number		*percent*					
Silk								
2	788	355	1.3	53.6**	3.1	60.7**	9.1	72.8**
10	688	345	1.6	73.5**	2.7	83.5**	9.3	89.7**
20	620	293	1.6	52.3**	3.4	71.1**	8.8	82.6**
40	716	275	1.2	15.4**	2.5	38.8**	8.5	58.9**
60[d]	661	340	1.0	4.0	2.8	11.5*	7.2	26.2**
Tip of ear								
2	914	359	1.9	89.8**	3.9	91.5**	10.6	94.3**
10	846	365	2.1	85.8**	4.0	97.9**	11.2	99.4**
20	821	338	1.2	70.4**	2.8	97.0**	10.1	98.4**
40	1026	357	1.4	28.4**	2.4	54.2**	8.7	87.8**
60	1133	444	1.2	4.0	2.9	12.1*	10.6	33.7**
Husk								
10	634	319	1.3	38.3**	2.6	48.4**	9.2	62.9**
20	598	341	1.1	21.4**	2.1	48.8**	10.5	72.6**
40	597	312	.8	3.9	1.8	11.5**	10.1	35.7**
60	572	284	1.2	1.1	2.2	5.6	8.7	21.4**
Shank								
2	1053	393	1.1	45.7**	2.1	62.6**	9.0	72.3**
10	1219	411	1.0	44.7**	2.4	67.6**	9.1	78.9**
20	1207	401	1.3	14.2**	1.6	45.7**	8.1	70.8**
40	1178	438	1.4	4.3	2.2	19.3*	7.4	62.3**
60	1172	583	1.6	2.4	2.4	7.7	9.1	22.6*
Leaf								
2	942	437	1.1	10.9**	2.5	21.8**	9.2	45.0**
10	901	445	1.7	6.1*	2.4	12.3**	8.4	42.7**
20	745	397	1.2	4.8	1.9	12.5**	8.6	31.1**
40	793	385	1.3	2.0	2.7	6.0	7.3	18.9*
60	749	405	1.2	1.9	1.8	3.1	6.9	15.3
Stalk								
2	998	458	1.0	2.6	2.7	10.7*	8.8	37.7**
10	989	449	1.1	2.5	2.7	7.7	8.1	35.6**
20	919	402	1.3	2.5	2.2	9.7*	9.3	31.0**
40	975	404	1.4	3.5	2.6	8.2	10.8	21.7*
60	807	403	1.1	1.6	1.8	4.5	8.6	17.2

[a] Diplodia-rot-damaged ears plus ears having Diplodia seed infection not evident as rot.

[b] See pages 57 to 59 for descriptions of how inoculations were made.

[c] Treated with sterile water in the same way that inoculations were made.

[d] Average grain moisture, 28.2 percent.

* Indicates a significant increase over the check at the 5-percent level, based on conversions to angles.

** Indicates a significant increase over the check at the 1-percent level, based on conversions to angles.

which include ears with infected kernels not visible as rot (Table 9). The tip-of-ear inoculations were the most effective, followed in decreasing order by silk, shank, husk, leaf, and stalk inoculations. When the corn was mature, assuming 30 percent grain moisture to denote maturity (60 days after silking), only the leaf and stalk inoculations caused no significant increases in ear infection. Ten days after silking was the most effective date for silk, tip-of-ear, husk, and shank inoculations. On the other hand, 2 days after silking was the most effective date for leaf and stalk inoculations. Among rot-damaged ears, the early inoculations ordinarily resulted in the highest proportion of completely rotted ears, later inoculations causing more partially rotted ears.

In general these results agreed very well with similar tests started in 1926 and conducted for a number of years with Reid Yellow Dent open-pollinated corn (23).

The spray method of inoculation. This method was first used by Burrill and Barrett (3) and was later developed more fully by Ullstrup (56). In Illinois tests the amount of Diplodia ear-rot development from spray inoculations was considerably above the checks but less than from the medicine dropper method. The latter method gives a measurement primarily of physiologic resistance within the ears themselves, while the spray method involves husk protection of the ear also.

One test for comparing results from the spray method of inoculation with other methods was made in 1946 when four single crosses were used, all of them having Ill. Hy2 in common (Table 10). According to data from natural infection (28), Ill. R4 ranks as resistant, Kan. K155 and Ind. 38-11 as intermediate, and Ind. P8 as highly susceptible when used in crosses. By the spray technique, only R4 × Hy2 was uniformly low in rot damage. Differentiation in reaction to Diplodia was better than by the medicine dropper method.

In 1948 five single crosses were used, four of them having Kan. K155 in common (Table 11). The inbreds involved, when used in crosses, ranked in susceptibility to natural Diplodia infection as follows: Ill. R4 and Ia. 701, resistant; Ill. Hy2 and Kan. K155, intermediate; and Ind. Tr and Ind. P8, highly susceptible (28). When tested by the spray method, hybrids derived from the combination of two resistant inbreds developed the least rot; one resistant inbred contributed a proportionate amount of resistance; and the hybrid carrying the highly susceptible inbred, P8, had the highest percentage of rot. When inoculations were made with a medicine dropper 30 days after silking, only the combination involving two resistant inbreds showed outstanding superiority.

Table 10. — Effectiveness of Various Methods of Inoculating Corn Ears; Three Fungi and Four Hybrids, Urbana, 1946

Fungus, inoculation method, and time of inoculation (days after silking)	Rot-damaged kernels[a]			
	Hybrid R4×Hy2	Hybrid K155×Hy2	Hybrid 38-11×Hy2	Hybrid P8×Hy2
Diplodia zeae		*percent*		
Spray				
10	5.9[b]	8.6[b]	8.7[b]	9.5[b]
20	9.9[b]	20.7[b]	17.6[b]	18.3[b]
30	.6[b]	3.4[b]	1.6[b]	2.6[b]
Medicine dropper[c]				
20	93.3[b]	94.6[b]	96.8[b]	97.4[b]
30	75.9[b]	95.8[b]	90.6[b]	92.4[b]
Gibberella zeae				
Spray				
10	.1	.3	.1	1.8[b]
20	.1	.4	.4	.7
Medicine dropper[c]				
10	8.4[b]	7.8[b]	6.5[b]	17.3[b]
20	2.0[b]	2.9[b]	1.0	2.5[b]
Oat kernel[c]				
20	5.2[b]	7.8[b]	2.6[b]	8.2[b]
Physalospora zeae				
Spray				
10	0	.1	.1	.2
20	.1	.1	.2	1.2
Medicine dropper[c]				
10	.3	.9	.8	2.1[b]
20	.3	.7	.9	1.4
Oat kernel[c]				
20	.5	2.7[b]	2.0[b]	16.4[b]
None	.2	.5	.3	.6

[a] Ears were shelled and sampled, and rot-damaged kernels were plated to identify the cause.

[b] Rot caused predominantly by the fungus used for inoculation.

[c] Husks were opened slightly so that spore or mycelial suspension or culture on oat kernel could be put directly on the tip of the ear.

In both years, when the spray method was used, the highest percentages of rot were obtained from inoculations made 20 days after silking. Inoculations made 30 days after silking were too late for good results in 1946. Differential reactions were good at 10 or 20 days after silking in both years. According to Ullstrup (56), "the best differential infections were obtained when inoculations were made within a period extending from a few days after full silk until about 2 weeks later." His results agree with those reported here that there is less rot when inoculations were made as long as 30 days after silking.

Ears inoculated repeatedly, 10, 20, and 30 days after silking, generally had more rot damage than ears inoculated only once. A maxi-

Table 11. — Effectiveness of Corn Ear Inoculations With Three Fungi on Five Hybrids, Made by Several Methods, Urbana, 1948

Fungus, inoculation method, and time of inoculation (days after silking)	Ears completely rotted by same fungus as used for inoculum					All rot-damaged ears caused by same fungus as used for inoculum				
	Hybrid 701× R4	Hybrid K155× R4	Hybrid K155× Hy2	Hybrid K155× Tr	Hybrid K155× P8	Hybrid 701× R4	Hybrid K155× R4	Hybrid K155× Hy2	Hybrid K155× Tr	Hybrid K155× P8
						percent				
Diplodia zeae										
Spray										
10	3	23	28	31	30	4	28	34	36	35
20[a]	9	39	69	67	70	11	41	78	75	81
20[b]	6	31	62	63	74	11	36	82	77	84
30	2	10	38	33	52	9	16	76	57	75
10-20-30[c]	14	52	69	69	79	25	62	86	82	95
Medicine dropper										
10	98	100	100	100	100	98	100	100	100	100
20	76	100	100	100	100	95	100	100	100	100
30	32	97	98	99	100	50	99	99	99	100
Gibberella zeae										
Spray										
10	0	0	0	0	0	0	1	2	1	1
Medicine dropper[d]										
10	0	1	2	2	5	17	38	49	58	78
Oat kernel										
10	0	3	6	5	5	51	73	76	73	83
20	0	0	0	0	0	0	4	1	3	1
Physalospora zeae										
Oat kernel										
10	8	35	36	18	10	11	41	40	20	12
None										
(Diplodia rot)	0	0.1	1.6	1.2	1.7	0.1	0.4	2.4	2.2	3.2
(Gibberella rot)	0	0	0	0	0	0	0	0.3	0.2	0.3
(Physalospora rot)	0	0	0	0	0	0	0	0	0	0

[a] Inoculations were made in the forenoon of a hot day, maximum temperature 98°F.

[b] Inoculations made near sun-down of the same day.

[c] The same ears were inoculated at three different times.

[d] Husks were opened slightly so that spore suspension or culture on oat kernel could be put directly on the tip end of the ear.

mum temperature of 98° F. on a day that inoculations were made did not adversely affect results (Table 11). Diplodia inoculations were more successful in 1948 (Table 11) than in 1946 (Table 10). It may be noted from these tables and other data (Fig. 23), that natural ear-rot prevalence also was exceptionally low in 1946.

Differential reaction between susceptible and resistant hybrids. When the hybrid CI.540 × Ill. R4 was inoculated in the ear shank or in the stalk with Diplodia (Fig. 32D,F), it developed more ear rot than a number of hybrids that ordinarily are much more susceptible. Although 540 × R4 is resistant to Diplodia ear rot, it is very susceptible to Diplodia stalk rot. The shank and stalk inoculations no doubt made it easier for the fungus to reach the base of the ear. We may conclude, therefore, that inoculations in the shank are not valid for testing ears for resistance.

On the other hand, when inoculations were made directly on the silks or tip of the ear, with either a spray nozzle or a medicine dropper, the comparative susceptibility ratings of hybrids frequently have been similar to ratings by natural infection.

To further test factors that might influence the differential action of hybrids, an experiment was made on the combined effects of time of

Table 12. — Diplodia Ear-Rot Development in Susceptible and Moderately Resistant Hybrids From Tip-of-Ear Inoculations Made at Different Times and With Different Spore Concentrations of *Diplodia zeae*, Urbana, 1942

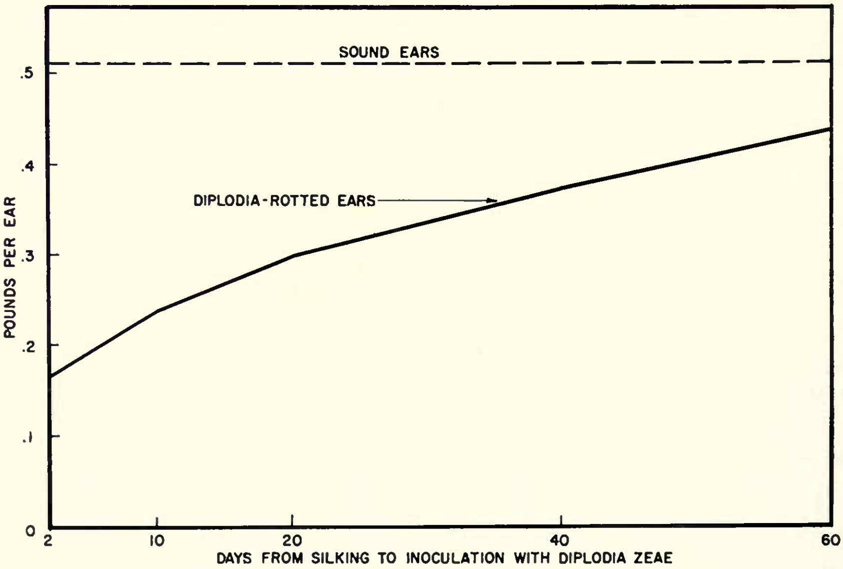
Time of inoculation (days after silking) and spore concentration	Diplodia-rot-damaged ears			Reduction in rotted ears from use of resistant hybrids
	Susceptible hybrids[a]	Resistant hybrids[b]	Difference	
10 days		*percent*		
Normal	100.0	100.0	0	0
1/10	99.7	98.5	1.2	1.2
1/100	98.9	93.5	5.4*	5.5
20 days				
Normal	100.0	86.5	13.5**	13.5
1/10	99.5	82.0	17.5**	17.6
1/100	96.7	81.0	15.7**	16.2
35 days				
Normal	82.5	53.8	28.7**	34.8
1/10	79.2	49.3	29.9**	37.8
1/100	66.9	37.6	29.3**	43.8
Check, ears not inoculated	6.5	1.9	4.6	70.8

[a] Average of single cross Ind. Tr x CI. 187-2 and double cross Ill. 201.
[b] Average of single cross CI. 540 x Ill. R4 and double cross Ill. 960.
* Indicates a significant difference at the 5-percent level, based on angle conversions.
** Indicates a significant difference at the 1-percent level, based on angle conversions.

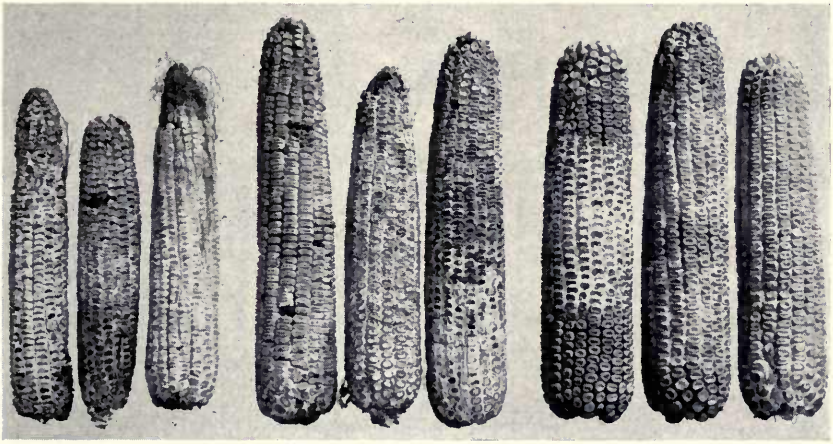
inoculation and of different spore concentrations (Table 12). Inoculations were made on the tips of the ears with a medicine dropper. The normal suspension was very dark with spores while the 1/100 dilution had only very slight turbidity.

When inoculations were made 10 days after silking with a normal suspension, all ears were rot-damaged and thus there was no differentiation between susceptible and comparatively resistant hybrids (Table 12). With the 1/100 dilution used the same day, differentiation was great enough to be statistically significant. Better differences were found when inoculations were made 20 days after silking, and still better at 35 days. Decreasing the concentration of the spore suspension consistently caused some decrease in percent of rot-damaged ears, but lengthening of the time after silking had a more pronounced effect on the differentiation between susceptible and resistant hybrids.

Effect of Diplodia rot on ear and kernel weights. Most of the corn ear-rot diseases may cause some reduction in weights of ears or grain, but this effect has been measured only for rot caused by *Diplodia zeae.* The first experiment was made with the station strain of Reid Yellow Dent corn for 4 consecutive years. Inoculations were made by placing the spores directly on the kernels at the tip ends of the ears at various



Weight of Diplodia-rotted ears when inoculations were made on the ear tip at various times after silking. Station strain of Reid Yellow Dent corn, 4-year average, 1931-1934. (Fig. 34) times after silking, and thus the weights of ears could be related closely to the time when infection took place. Rot-damaged ears typical of those obtained from each inoculation time, together with representative sound ears, were selected when mature, and then dried. Nubbins, imperfectly developed ears, and ears damaged by other kinds of rots or by worms or birds were discarded. Results were measured on the basis of average ear weights.



Appearance of Diplodia-rotted ears when inoculations had been made on the tips 2, 20, and 40 days after silking. Ears inoculated 2 days after silking showed the greatest loss in weight. (Fig. 35)

Greatest loss in weight took place in corn that was inoculated 2 days after silking, when ears had not yet made much growth. These ears weighed only one-third as much as the mature checks (Figs. 34, 35). Rotted ears resulting from inoculations made 10 days after silking weighed about half as much as the checks. At still later dates a lower percentage of ears became rotted, but the weights refer only to the rot-damaged ears. These were increasingly heavier as the time of inoculation was delayed. According to other investigators also, Diplodia rot has caused a 50-percent or greater reduction in ear weight (14, 65).

Some years later an experiment on the effect of Diplodia rot on kernel weights was conducted with four hybrids, two of them comparatively resistant and two of them susceptible. Four inoculation dates were used. The ears were selected and dried as in the previous experiment. Two hundred kernels were taken from the middle portion of the rotted area of each of 10 ears harvested from each of four replications.

Table 13. — Weight of Corn Kernels of Four Hybrids When Tip-of-Ear Inoculations Were Made With a Spore Suspension of *Diplodia zeae* at Various Times After Silking, Urbana, 1941

Days after silking when inoculated	Somewhat resistant hybrids			Susceptible hybrids		
	Ill. 960	540× R4	Aver.	Hy2× Tr	Hy2× 187-2	Aver.
Average weight per kernel, grams						
10	.209	.164	.186	.187	.185	.186
20	.221	.201	.211	.248	.207	.228
30	.262	.204	.233	.269	.236	.252
40	.290	.245	.267	.292	.253	.272
Check, sound ears	.303	.243	.273	.327	.288	.308
L.S.D. at 5-percent level	....	....	.031	....	....	.032
Decrease in weight from rot, percent						
10	28.7	35.0	31.8**	42.6	36.9	39.7**
20	26.8	14.2	20.5**	22.5	29.5	26.0**
30	14.1	13.7	13.9*	17.6	18.2	17.9**
40	6.1	1.2	3.6	10.4	7.9	9.1*

* Significant decrease at the 5-percent level.
** Significant decrease at the 1-percent level.

For corresponding time intervals after silking, the reduction in weights of kernels in this experiment (Table 13) were not as great as the reduction in weight of ears in the earlier experiment (Fig. 34). The reason for this is not clear. However, here again Diplodia rot caused increasingly less loss in weight as time of inoculation became later.

A striking result from this experiment was that the susceptible hybrids consistently lost more weight as a result of rot than the comparatively resistant hybrids, when inoculations were made at the same time intervals after silking.

The data given in Fig. 34 and Table 13 can be used to determine the approximate time when infection took place, provided the approximate loss in ear or kernel weight is known. The loss in weight is caused to a considerable extent by the arrested development of the ears.

Fusarium Moniliforme Inoculations

Preparation of inoculum. The spore suspension used was a mixture of five different isolates chosen for their vigorous growth in culture and for variation between isolates in colony appearance. The cultures were grown separately on potato dextrose agar slants for 10 to 14 days.

Spore suspensions in sterile water were prepared, mixed, and filtered through 60-mesh voile. About 20 milliliters of water was used per tube and no further dilutions were made. The isolates used in different years were not always the same and none of them were tested for pathogenicity before the start of the experiment.

Results from inoculations. Inoculations were made on the silks, on tips of ears, beneath the outer husks, and in the shanks, using a medicine dropper or syringe as described under "Methods of Inoculating." Checks were treated in the same manner with sterile water. Inoculations were not made in the leaf axils and in the stalks as it had been shown earlier (23) that inoculations in these spots were entirely ineffective for this fungus. The spray method (Fig. 33) was also tried extensively, but when used without opening the husks it was ineffective in producing kernel rots.

The number of ears used was roughly similar to the number used for the Diplodia inoculations (Table 9). Ears were recorded as rotted only when 10 or more kernels were rot-damaged. Separate classes were made of (a) ears with rot at the tip end only, (b) ears with scattered rotted kernels, and (c) all Fusarium-infected ears, including ears having kernels with infection not visible as rot.

Inoculations made with a medicine dropper on the silks of Reid Yellow Dent caused a little increase in rot (23). In later tests with hybrid U. S. 13, which might be considered to be equally susceptible, this method caused no significant increase in rot (Table 14). Silk inoculations, however, did cause highly significant increases in infected ears, as determined by surface sterilizing and plating 10 representative kernels from each ear.

Tip-of-ear inoculations, when done within 20 days after silking, were most successful in increasing rot and kernel infection. There were significant increases in tip-of-ear rot, and highly significant increases in scattered rot and in total of all Fusarium-infected ears. The increases occurred over the checks even though the amount of Fusarium rot and seed infection had also increased in the checks (Table 14). Such increases in the check usually occurred when sterile-water treatments had been made on the tip of the ear 2 and 10 days after silking. Increased Fusarium rot from tip-of-ear treatment of the checks with sterile water had also occurred in the earlier experiments (23), but this was not reported. This led to experiments on opening of husks without the addition of water or inoculum (Table 6) as a method for increasing ear rots and obtaining better differential reactions between

Table 14. — Fusarium Ear Rot and Ear Infection Resulting From Pure Culture Inoculations Made With *Fusarium moniliforme* at Different Locations on the Plant at Different Times; Hybrid U. S. 13, Urbana, 4-Year Average, 1939-1942

Place and time of inoculating (no. of days after silking)[b]	Ears with Fusarium rot						All Fusarium-infected ears[a]	
	Rot at tip of ear only		Scattered rot		Total of both types of rot			
	Check[c]	Inoc.	Check[c]	Inoc.	Check[c]	Inoc.	Check[c]	Inoc.
				percent				
Silk								
2	5.2	6.9	2.1	2.3	7.3	8.8	46.8	51.7
10	4.8	6.2	2.8	2.1	7.6	8.3	46.6	70,9**
20	4.4	7.1	2.6	3.9	6.9	11.0	41.8	59.1**
40	4.8	6.6	2.4	3.2	7.3	9.6	35.5	51.8**
60	3.7	4.1	1.8	2.1	5.5	6.1	33.9	42.4*
Tip of ear								
2	8.5	13.8*	8.5	20.1**	17.0	34.9**	60.5	91.4**
10	6.6	12.7*	5.7	19.3**	13.4	32.1**	58.8	88.0**
20	6.5	12.6*	2.6	8.9**	7.0	24.0**	48.6	70.6**
40	5.6	11.1*	2.3	3.1	7.9	14.2*	37.8	53.0**
60	5.4	8.5	2.7	2.0	8.1	10.5	40.9	43.5
Husk								
10	3.8	7.0	4.0	4.3	7.8	11.3	41.7	43.4
20	5.0	6.8	3.7	5.8	8.7	12.6	44.7	47.4
40	3.6	6.8	2.3	5.6	5.9	12.4*	37.2	44.2
60	4.2	4.3	2.5	3.3	6.7	7.6	37.9	34.6
Shank								
2	4.3	4.2	2.9	3.0	7.2	7.1	43.0	47.3
10	4.5	5.3	2.6	3.2	7.1	8.5	38.2	41.5
20	4.7	8.8	2.2	3.8	6.9	12.6	38.1	42.8
40	6.4	8.5	2.4	1.8	8.8	10.3	36.7	35.2
60	5.0	6.2	3.0	2.3	7.9	8.5	34.6	34.5

[a] Fusarium-rot-damaged ears plus ears having Fusarium seed infection not evident as rot.

[b] See pages 57 to 59 for descriptions of how inoculations were made.

[c] Treated with sterile water in the same way that inoculations were made.

* Indicates a significant increase over the check at the 5-percent level, based on conversions to angles.

** Indicates a significant increase over the check at the 1-percent level, based on conversions to angles.

resistant and susceptible hybrids. Edwards (11) also noted that his checks treated with sterile water had more *Fusarium moniliforme* infection than checks with undisturbed husks.

Inoculations made between the husks and in a puncture in the shanks caused little increase in kernel rot or infection (Table 14).

Differential reaction between susceptible and resistant hybrids. Studies were made of two hybrids susceptible to Fusarium ear rot and two that were comparatively resistant, to determine whether the difference between them could be accentuated by inoculation with a spore suspension. Ear rot of both groups was greatly increased by inoculating on the tip of the ear 10 days after silking. Each later inoculation produced less rot, until at 50 days the inoculated ears had no more rot than the checks. The greatest difference in amount of rot-damaged ears between the susceptible and comparatively resistant hybrids also occurred at the earliest inoculation and diminished with delay in inocu-

Table 15. — Fusarium Ear Rot Development in Susceptible and Moderately Resistant Hybrids From Tip-of-Ear Inoculations Made at Different Times With Pure Cultures of *Fusarium moniliforme*; Urbana, 1941

Time of inoculation (days after silking) and rating of hybrids	Ears in test	Grain moisture when inoculated	Fusarium-rot-damaged ears				Reduction in rotted ears from use of resistant hybrids
			Rot at tip of ear only	Scattered rot	Total, both types of rot	Difference between hybrids	
	number			*percent*			
10 days							
Susceptible[a]	323	77.8	11.8	73.4	85.2		
Resistant[b]	411	77.6	20.2	7.8	28.0	57.2**	67.1
20 days							
Susceptible	327	69.0	26.6	45.5	72.1		
Resistant	432	67.6	18.1	5.9	24.0	48.1**	66.7
30 days							
Susceptible	327	48.7	12.6	22.4	35.0		
Resistant	416	48.3	11.9	4.0	15.9	19.1**	54.6
40 days							
Susceptible	262	37.7	9.6	19.9	29.5		
Resistant	349	36.5	8.1	3.2	11.3	18.2**	61.6
50 days							
Susceptible	193	27.8	9.9	14.5	24.4		
Resistant	269	26.8	8.2	2.6	10.8	13.6**	55.7
Check, ears not inoculated							
Susceptible	563	....	12.3	13.5	25.8		
Resistant	829	....	8.8	2.2	11.0	14.8**	57.4

[a] Average of single crosses Ill. Hy2×Ind. Tr and Ill. Hy2×CI. 187-2.
[b] Average of single cross CI. 540×Ill. R4 and double cross Ill. 960.
** Significant at the 1-percent level.

lation. However, the relationship between the susceptible and resistant hybrids used in the experiment as measured by the percent reduction in rot-damaged ears remained nearly constant regardless of kind or absence of inoculation (Table 15, last column).

There were no consistent differences between the susceptible and resistant hybrids in rot at the tip of the ear only, but striking differences occurred in percent of ears having scattered rot-damaged kernels (Table 15).

Gibberella Zeae Inoculations

Preparation of inoculum. Isolations of *Gibberella zeae* vary considerably in pathogenicity and morphological aspects (54). Therefore, sporulating cultures of *G. zeae* were pretested for pathogenicity before they were used. Original isolations from corn stalks or ears usually sporulate poorly, but by making numerous single-spore isolates, a number of strains that sporulated well could usually be obtained, although these sometimes varied greatly in pathogenicity. The spore suspension inoculum was prepared by the same method as described for *Fusarium moniliforme*.

Oat-kernel inoculum of *G. zeae* was made in a similar manner to that described for Diplodia, but the cultures were used when only 10 to 14 days old. The oat-kernel inoculations were made by placing one of the infested kernels beneath the husks near the tip end of the ear.

Results from inoculations. The spray method was almost ineffective when used 10 or 20 days after silking (Tables 10, 11). Tip-of-ear inoculations with a medicine dropper or with oat kernels were effective when made 10 days after silking.

In an earlier inoculation experiment conducted for 4 years with Reid Yellow Dent (23), results from silk inoculations were erratic, causing some increase in rot in some years, and not in others. Tip-of-ear inoculations were effective every year when made during the first 10 days after silking but were considerably more effective in some years than in others. They were also effective in some years when made 20 days after silking. Kernel infection without rot symptoms increased more over the check than did kernel rot. Inoculations in the husks and the shank were ineffective.

Although only early inoculations were successful with this fungus by the methods used, Gibberella rot resulting from natural infection can increase in the fall under some conditions. In 1947, when Gibberella rot was comparatively high (Fig. 23), harvestings made October 1, November 1, and December 1 revealed .06, .16, and 1.33 percent, respectively, of Gibberella-rot-damaged kernels.

In Gibberella inoculation tests using various hybrids, single crosses involving Ind. P8 were most susceptible (Tables 10, 11). The cross Ill. R4 × Ia. 701 had some resistance while two other R4 crosses were intermediate in their reaction.

Physalospora Zeae Inoculations

Cultures of *Physalospora zeae* were grown 7 to 10 days on PDA medium in Petri dishes. The fungus and the agar from two dishes were then placed in a Waring blender together with 200 c.c. sterile water and blended for ½ minute. The suspension consisted of mycelial fragments because the fungus didn't sporulate.

Oat-kernel cultures also were prepared. These were made as previously described (page 59) and were used when about 10 days old. It was found that sometimes these cultures did not live long.

In 1945 hybrid U. S. 13 was inoculated by placing an oat-kernel culture either beneath the husks at the tip of the ear or in a hole in the shank. The hole had been made with a small cork borer an inch or more from the butt of the ear. Inoculations made 20 days after silking were very successful, the tip-of-ear inoculations producing 85 percent rot-damaged ears, and the shank inoculations, 34 percent. Of the damaged ears, 45 percent of those inoculated in the tip and 13 percent inoculated in the shank were blackened mummies (Fig. 13, right). Successively later inoculations produced progressively lower percentages of rot and no mummies. The later inoculations resulted largely in ears with a white mold resembling Diplodia (Fig. 13, left and center). Some of the shelled grain, however, showed some of the dark sclerotia characteristic of *Physalospora zeae* (Fig. 12C).

In 1946 and 1948 the inoculations caused less rot than in 1945. The tip-of-ear inoculations, however, were effective and were better when made 10 days after silking than when made later (Tables 10, 11).

Ullstrup (55), using a hypodermic syringe, inoculated ears of a single cross hybrid with a suspension of mycelial fragments of *P. zeae* 1 week after silking. Abundant ear rot was obtained.

Nigrospora Oryzae Inoculations

Cultures of Nigrospora that had been isolated from infected corn kernels were selected for their ability to sporulate abundantly in culture. These were grown on cooked oats, as described for Diplodia, and were used when about 2 weeks old. Spore suspensions also were made in the manner described for Diplodia.

Inoculations made on or in the silks, tip of ear, husk, and shank all caused small average increases in rot over the check (23). When inoculations had been made on the silks or tip of ear, sporulation at maturity was most prominent at the inoculated end of the infected ears. Inoculations beneath the husks or in the shank resulted in sporulation primarily at the butt end of the ears. *Diplodia zeae, Physalospora zeae,* and *Nigrospora oryzae* were the only fungi with which successful shank inoculations were made, but whereas *D. zeae* was a vigorous parasite, *N. oryzae* gave only a small increase in infected ears. *P. zeae* was intermediate in effectiveness as a parasite.

Reddy (40) reported some increase in Nigrospora ear rot from shank inoculations in a year when natural Nigrospora inoculum was not abundant. But in another year when natural inoculum was widespread, check ears had just as much Nigrospora infection as the inoculated ones. In such a case, Reddy stated, it was simply a matter of susceptible ears becoming invaded and resistant ones remaining free of infection.

Experiments were also made in Illinois to determine whether removal of leaves at the time of inoculation increases susceptibility. Some of the mutilations did increase Nigrospora ear-rot infection, both in the checks and in the inoculated plots. For example, when tip-of-ear inoculations were made 10 days after silking and all leaves above the ear were removed from check and inoculated plants at that time, ear weight at maturity was reduced 35 percent in the checks and 39 percent in inoculated plants as compared with normal plants. In uninoculated but mutilated plants, 4.4 percent of the ears revealed Nigrospora spores as a result of infection while in the inoculated plants the percentage was 7.3. In normal plants, the corresponding percentages were 0 and 0.4.

DISCUSSION

Only certain methods, results, and observations seem to need a fuller discussion than that already given earlier in this bulletin.

General

Moisture relations. Rainfall is the principal factor contributing to the great variations between years in amount of ear-rot damage in Illinois. Late planting may be a factor and usually it is the result of excessive rain during the springtime. Early frost, when ear-moisture content is still high, is another seasonal characteristic that may influence rots.

High moisture in August and September apparently increases ear rots by increasing the production of inoculum, and by washing the spores down among the husks or between the husks and ear when the ear tip is exposed. Also, high humidities favor spore germination and infection. High moisture in October increases ear rot for these reasons: It retards the normal drying of the ears, thus keeping them in a susceptible condition for a longer time; the husks may be very loose and pockets of moisture may form next to the ears; and there is more lodged corn and some ears may be in contact with the wet soil.

Moisture control after harvest is feasible and important. This is discussed on page 81.

Size of experimental field plots. Coefficients of variability were calculated for yield of grain and percent of rot-damaged kernels from a 3-year test involving four hybrids. Individual plots were 14 hills in size, and entries were replicated seven times. Ear rots occurred from natural causes in a normal manner. The average coefficients for yield and damaged kernels were 10.6 and 60.5, respectively, indicating that rot damage was nearly six times more variable than yield. Therefore, in order to obtain reasonably accurate data on prevalence of naturally occurring rot damage, higher plant populations are needed and plots should be replicated more frequently than is the usual practice for obtaining yield data. Significant difference in rot damage was obtained in some of the experiments only because differences in rot damage were much greater than differences in yield.

Ear versus kernel examination methods. Both methods have advantages. Ear examinations require the least time and the ears can be classified according to the kinds of rot involved. Compared with classifications on the kernel basis, ear separations are at times reasonably accurate for some rots, as for instance, Diplodia rot. However, even for Diplodia, the difference between the two methods may sometimes be significant (Table 8).

Values for the amount of rot caused by *Fusarium moniliforme* have been considerably higher by the ear-examination than by the kernel-sorting method. This is because much of the Fusarium rot occurs as scattered kernels among sound ones. Examination of Figs. 22 and 23 will show how the two methods compared in indicating the amounts of Diplodia rot and Fusarium rot in 1940 and 1941.

Comparisons between ear examination and kernel sorting as methods of indicating total rot damage are given in Table 5. The greatest differences between the two methods in results obtained with ears from standing stalks were in the varieties (hybrid B and open-pollinated B) that had the most Fusarium rot.

In studies on errors involved in sorting kernels, it became clear that either the operator must have no knowledge of what results to expect, or the samples must be identified only by code. Also, he must not have the data available for other replications of the same item previously sorted by him. It is highly important that the work not be hurried.

Errors in the determination of rot prevalence depend not only on the human element. For example, early rot damage caused by *Diplodia zeae, Gibberella zeae,* or *Physalospora zeae* may result in as much as 50 percent reduction in kernel weights. With some shellers most of the lightweight damaged kernels may go out with the chaff, or even if they are saved and weighed, there will not be a full realization of the damage.

Although the determination of rot damage by the kernel-sorting method will not identify the kinds of rot involved, such knowledge may not always be important. A determination of specific rots requires much more time and certain kinds of laboratory facilities as mentioned earlier under the heading, "Methods" (page 30).

Open versus closed husks. Some inbreds contribute much better husk protection to a cross than others (Fig. 27). There seems to be no doubt that, other things being equal, a tendency for ears to be well protected until maturity is associated with a lower amount of ear rot (Tables 3, 4).

In a publication (28) on the rating of inbreds for ear rots, husk protection, and ear declination as determined in single and three-way crosses, all the inbreds that contributed good husk protection when in the early dent stage also rated in the upper half of the scale for resistance to Diplodia and Fusarium ear-rot damage at maturity. However, some inbreds contributing poor husk protection also rated in the upper half of the scale, indicating that they imparted a very good inherent resistance to crosses.

Despite the advantage of good husk protection in lowering the incidence of rot, some seed producers prefer hybrids with husks that open early, so ears will dry faster. The two desired results are thus in direct opposition to each other. This dilemma can be resolved only by developing hybrids highly resistant to ear rots, or hybrids with ears that dry satisfactorily in closed husks.

Aids in Breeding for Ear-Rot Resistance

Concentrated efforts in breeding for ear-rot resistance have, to the writer's knowledge, not yet been made. Inbreds that contribute superior resistance to crosses for Diplodia, Fusarium, and other ear rots have been observed in the tests made (*see* page 40). Unfortunately none of these are in wide use because most of them are deficient in other characteristics.

Testing inbreds for resistance. Further experiments on methods for testing inbreds are needed. When relying on natural infection, the writer found poor correlation between the results when inbreds were tested as such, and when they were tested in hybrid combinations. Similar results for Diplodia rot were reported by Smith and Trost

(46). However, they obtained considerably improved resistance to Diplodia ear rot in some inbred strains of sweet corn by selecting for freedom from infection during the first 5 years of inbreeding. Wiser (67), using the spray inoculation technique with *D. zeae,* also found a poor correlation between the amount of ear rot in inbreds tested as such, and the amounts obtained when they were tested in hybrid combinations.

Working in Iowa, Hooker (16) reported results for 2 years on the percentages of Diplodia and Gibberella ear rot caused by natural infection in 25 corn inbreds. Ten of the inbreds were the same as those tested for Diplodia rot in Illinois (28). Inbreds were tested as such in Iowa and in crosses in Illinois. There was no correlation between the results from these tests. Furthermore, among the 25 inbreds tested in Iowa, there was no correlation between the 2 years in percentages of rot caused by either *D. zeae* or *G. zeae.*

Somewhat better correlations were obtained between results in Illinois and in California when inbreds were tested for susceptibility to *Fusarium moniliforme.* Inbreds were rated as inbreds in California (45) and in crosses in Illinois (28). Eighteen inbreds were the same in both locations. In spite of differences in methods of testing and in climate, 11 of the inbreds occupied a somewhat similar ranking in Illinois as in California. Of the others, 3 ranked as more resistant in Illinois, and 4 as more susceptible.

Though some method of testing for resistance of inbreds is needed, the final evaluation should no doubt be based on their reaction in hybrid combinations. This may be done in systematic single crosses, in backcrosses involving a common recurrent line (67), or in three-way crosses, in which the inbreds being tested are crossed with several unrelated single crosses used in common as testers. The use of double crosses as testers might also be considered. Any of these methods will narrow the range from resistance to susceptibility, as compared with the true values of the inbreds tested, but they will establish the relative rankings of the inbreds. When a considerable number of inbreds are to be compared, the tester method, used fairly often by the writer, appears to provide the most information on inbreds at the least expense.

There is little doubt that variations in seasonal and climatic conditions also affect the relative resistance imparted by inbreds. In addition, the reactions of inbreds are usually influenced not only by inherent resistance but by husk coverage and ear declination as well. Also, resistance imparted by an inbred depends to some extent on its combining ability for this character with other specific inbreds. Furthermore, it is known that inbreds in use by various people, although having the same name, often are not entirely the same.

Reliance on natural infection. Not only does the total amount of ear-rot damage vary greatly from year to year, but so do the causes of rot. Diplodia rot, for instance, may be prominent in one year and Fusarium rot in another (Figs. 22, 23).

The higher the prevalence of naturally occurring ear rot in a test plot, the better the differences in resistance can be measured. Natural infection with Diplodia can be expected to be more pronounced where corn is grown repeatedly on the same ground (Table 7). The corn should not be harvested too early (6, 20) for as long as the average grain moisture content is above 21 percent, rots continue to develop (Table 6).

If husks are opened at the ear tips 10 to 20 days after silking, a reliable evaluation of susceptibility to ear rot can be obtained from a smaller plant population than would otherwise be necessary (Table 4, Fig. 26). Increase in rot occurs not only in the exposed kernels but more or less throughout the ears. Thus, feeding by birds on the exposed part does not invalidate the test. Shelling the ears and sorting the kernels for discolorations caused by rot was found to be the best procedure when using the manual husk-opening method.

Ear inoculations. The spray method of inoculating ears appears to be successful only for *Diplodia zeae* as judged by the writer's experiments. Smith and Madsen (45) used the spray method with *Fusarium moniliforme* in California, but gave no information on how much, if any, rot was increased over that obtained with natural infection. Any of the other inoculation methods mentioned earlier also were effective with Diplodia. When testing for resistance, however, Diplodia inoculations directly on the tip of the ear should not be made before 30 to 40 days after silking. All very young ears appear to lack resistance to this fungus. The spray method should be used earlier because then the fungus does not gain immediate entrance into the ear.

Applying a spore suspension of *Fusarium moniliforme* with a medicine dropper, directly on the kernels at the tips of the ears, considerably increased the numbers of infected and damaged kernels, as compared with those naturally infected. These inoculations should be made not later than 10 to 20 days after silking. Differences in resistance to this fungus occur very early in the development of the ear.

Cultures on oat kernels applied to the tip of the ear were effective for making inoculations with *Fusarium moniliforme, Gibberella zeae,* and *Physalspora zeae*. *G. zeae* and *P. zeae* however, were effective only on susceptible hybrids and only while the ears were not more than a few weeks old.

In Minnesota toothpicks have been used to inoculate ears with *Diplodia zeae* and *Gibberella zeae* (7). About 7 days after silking, ears were wounded through the husks at about midpoint and a toothpick carrying the culture inserted. This method has not been tried in Illinois, but it may be good for determining inherent resistance when testing inbreds as such. However, as mentioned earlier, when *D. zeae* is used, it would seem that 7 days after silking is too early for obtaining good differential reactions between resistant and susceptible ears.

Since all corn ears gradually become less susceptible to rot damage as they develop, it is important that ears be in the same stage of development when inoculations are made for comparisons of resistance. When inoculations with Diplodia were made by the spray method, variations in time of silking apparently could be counteracted to a certain extent, because the most rot was obtained with inoculations made 20 days after silking. At earlier dates, the ears had more complete husk protection, which counteracted increased susceptibility of the ears. Hybrids differing as much as 10 days in silking could probably be compared satisfactorily by the spray method by making one inoculation on all entries 20 days after the first silks appear, and another inoculation 10 days later. When attempting to determine the resistance of individual ears, inoculations should probably be made still more frequently.

Ear inoculations with the various fungi used have not been equally successful in all years. In some years, inoculations with *Gibberella zeae* and *Physalospora zeae* produced almost no results.

CONTROL MEASURES

Ear Rots Occurring in the Field

Corn ear-rot diseases occurring in the field can be only partially controlled at present. Under some cultural and environmental conditions, the amount occurring is negligible, but losses can be high if the weather is wet while the ears are developing and maturing. Attention to a number of measures that affect ear-rot prevalence can make a difference in the actual amount of damage.

Some hybrids are less subject to the major ear rots than others. Among them are hybrids with ears that are well covered until maturity, as well as hybrids that resist lodging so that the ears will have no contact with the ground. Of greatest importance, however, is inherent resistance within the ears themselves. Differences in this character can be determined by carefully conducted tests. However, with the resources available it would be impossible to test all the commercial hybrids in use in Illinois as well as experimental hybrids. Testing the comparative prevalence of ear rot is considerably more time-consuming than making yield tests. Therefore, no recommendations concerning specific hybrids will be made here. At present, growers will need to rely on their seed producers or leaders for information on ear-rot resistance of hybrids. Better resistance than is now generally available is needed, and no doubt will be attained when breeding programs designed specifically for ear-rot resistance become effective.

A hybrid should be selected that is neither too early nor too late in maturity. Hybrids that mature comparatively early may be more subject to Diplodia ear-rot damage than those maturing normally (46). The husks loosen with ripening, allowing the fungus spores to enter early hybrids when the temperature is more favorable for fungus growth than it would be later in the season.

Hybrids with ears that dry rapidly in the fall have less Diplodia ear rot than those that dry slowly (59).

Field sanitation is helpful. Thoroughly turning under corn fodder while plowing is particularly important. Burrill and Barrett (3) reported finding Diplodia fruiting abundantly even on 2-year-old pieces of corn stalks lying in a clover field. All Diplodia ear infection and most of the Diplodia stalk infection originates from air-borne spores. Covering old diseased refuse with soil keeps the spores from becoming air-borne and also discourages their development.

The value of crop rotation for combatting Diplodia ear rot, particularly breaking the corn-after-corn sequence, has been mentioned by various investigators (3, 6, 8). Data from experimental plots in Table 7 give further support to these conclusions. As the ear infection originates entirely from air-borne spores, the effect would no doubt be more noticeable in corn fields larger than the ones used in these experiments.

Good drainage facilities not only are desirable for good corn production but also help to reduce several diseases.

The soil fertility should be in good balance, but whether or not the level is high or low, within a reasonable range, appears to make little difference in the incidence of most rots. A generous supply of phosphorus was found to reduce Fusarium ear rot (Table 7).

Ear Rots Occurring in Storage

Rots developing in the crib and in other storage facilities can be controlled satisfactorily with suitable equipment. Since apparatus for rapidly drying seed corn has come into general use, fungus infection in seed corn has been greatly reduced. Early harvesting and rapid drying of market corn (60, 62) reduces the moisture and checks the development of "total damage," and thus the grade is improved. Early harvesting at a high ear-moisture content and cribbing without forced air drying is of no help, for the ears usually dry more rapidly in the field than in the crib. However, from late fall or early winter until sometime in March, temperatures in Illinois are usually low enough that there is little fungus growth and ears with a reasonably high moisture content will be relatively safe in cribs. In order to avoid spoilage as spring weather approaches, the ears must undergo sufficient drying during the winter months.

For proper handling of corn, and details concerning cribs and driers, the reader is referred to other publications (42, 61, 63). Suffice it to say here that, on the average, if the grain moisture of ear corn is not over 20.5 percent when harvested, corn can be cribbed safely in naturally ventilated cribs properly designed for the geographical area where located (8 feet wide in central Illinois). If the grain moisture is somewhat higher, some auxiliary ventilation devices such as A-frames or latticed tubes within the crib generally help. Forced ventilation with unheated air will frequently be adequate for ear corn having up to 30 percent moisture. For still higher moistures, heated forced air is needed. Under unusually wet weather conditions, heated forced air is the only safe method for drying corn having more than 20 percent moisture.

For long-time storage, including subjection to summer temperatures, the grain moisture of ear corn should not be over 14 percent in order to be safe from attack by molds. Shelled corn should not be over 13 percent and needs to be watched so that remedies can be applied if damp areas develop. Vigilance against insect attack in stored corn also is needed. Insect activity tends to increase the moisture in corn, and this in turn tends to support mold growth. Molds are likely to increase both moisture and temperature in corn.

SUMMARY

Descriptions and other information are given for ear and kernel rots or molds operating in the field or in storage. Species of ten genera of fungi are discussed as causes of these hazards.

Three methods of assessing ear-rot damage were used in making interannual comparisons of prevalence:

1. Ears were sorted on the basis of ear symptoms.

2. Kernels in shelled corn were sorted according to symptoms of rot damage. The causal organisms were sometimes isolated and identified.

3. Data were obtained from licensed grain inspectors at terminal markets on the percent of car loads grading more than 5 percent damage in June.

The first two methods were also used to evaluate the results of many field experiments.

Large variations in prevalence of ear rots were found in different years. On the basis of corn received at terminal markets, it would seem that from 1930 to 1956 no noticeable improvement was made in control of rot damage.

The average annual loss from corn ear rots in Illinois, considering market discounts and impaired feeding value, was estimated at about 1½ million dollars.

Correlations of variability among hybrids were nearly six times greater for ear-rot injury due to natural infection than for yields of grain, indicating a need for more replications and more plants in experiments designed to make ear-rot evaluations.

When ear rots were caused by natural infection, poor correlations were obtained between ear-rot evaluations in inbreds tested as such, and the same inbreds tested in hybrid combinations.

Some inbreds that transmit fairly good ear-rot resistance to a cross are known, but because they possess other undesirable characteristics, they are not used much commercially. However, some hybrids in wide use are less susceptible to ear rots than others.

Rainfall during August, September, and October was found to be the most important factor influencing the prevalence of ear rots. Correlations between ear rot and rainfall for each of the 3 months showed that September was the most important, the other 2 months being about equal. The most highly significant correlations were obtained when the averages for the 3 months were used.

The more intensive and continuous the cropping to corn, the higher was the percentage of Diplodia rot.

Supplying an adequate amount of phosphorus to the soil reduced ear rot caused by *Fusarium moniliforme.*

Ears in a declined position during maturation and ears well covered by husks had less rot than ears that were upright or had open husks. When husks were hand-opened at the tip of the ear about 20 days after silking, the prevalence of all ear rots was greatly increased. When husks were opened 10 or more days later, the increase in rots was progressively less.

Physical damage to corn ears by ear worms was followed by increased rots, especially those caused by *Fusarium moniliforme* and *Penicillium* species.

When plants were lodged so that the ears were flat on the ground, ear rots from all causes were greatly increased. The earlier the lodging, the higher the amount of disease. Rots caused by *Nigrospora oryzae* and *Alternaria* sp. particularly were increased in ears having extensive contact with the soil, and rot caused by *Trichoderma* spp. occurred only in such ears. Varieties that had the most ear rot in standing corn also had the most in lodged corn.

Corn ear inoculation experiments were made with the primary object of finding methods for obtaining better differentiation between susceptible and resistant inbreds and hybrids. Inoculations were made with a number of fungi, at various time intervals after silking, at various locations on or near the ears, and by various methods of applying the spores or mycelium of the fungus.

Diplodia zeae was the most aggressive parasite used. Successful inoculations were made from 2 to 60 days after silking, with the highest percentage of rot-damaged ears occurring when inoculations were made at the tip of the ear 10 days after silking. It was the only fungus that caused a significant amount of rot when the inoculum was applied with a spray nozzle and the husks were not opened. Also, it was the only fungus that increased ear rot when inoculations were made in the stalk close to the shank-bearing node.

Diplodia zeae, Physalospora zeae, and *Nigrospora oryzae* were effective, in decreasing order, in causing ear rot when inoculations were made in the shank.

Ears were most susceptible to *Fusarium moniliforme* 2 days after silking and continued to be susceptible in lessening degree until 40 days after silking. Placing a spore suspension or some of the fungus culture directly on the kernels near the tip of the ear was the most successful method tried.

Inoculations with *Gibberella zeae* were successful when a spore suspension was applied with a medicine dropper or a piece of the fungus culture was applied directly on the kernels near the tip end of the ear 10 days after silking. Inoculations made 10 days later frequently were too late.

Inoculations with *Physalspora zeae* on the ear tips were successful when made 10 days after silking. They also were somewhat successful when made 20 days after silking, but not at later dates.

Among Diplodia-rotted ears produced by artificial inoculation at the same stages of ear development, ears and kernels from susceptible hybrids were lighter in weight at harvest time than rotted ears or kernels produced by more resistant hybrids.

All hybrid combinations tested were highly susceptible to Diplodia ear rot when spore suspensions were applied on the tip of the ear with a medicine dropper within 20 days after silking. Inoculations made 30 to 40 days after silking, however, gave good differential reactions in amount of rot between resistant and susceptible varieties. When tip-of-ear inoculations were made using *Fusarium moniliforme,* differences in resistance were observed at all stages of ear development, with the greatest differences resulting from inoculations made 10 or 20 days after silking.

In years when natural Fusarium and Diplodia rot damage was average or above average, the relation between resistant and susceptible hybrids in percentage of damaged kernels was about the same as when artificial inoculations were made. The advantage of artificial inoculations was that they assured the occurrence of rots and made it possible to obtain a corresponding amount of accuracy from smaller plant populations.

Methods that might be used by corn breeders to increase ear rots caused by natural infection and thus facilitate selection for ear-rot resistance are: continuous cropping to corn, late harvesting, and early artificial opening of the husks at the tips of the ears.

Suggestions for ear-rot control include use of resistant hybrids, thorough plowing under of crop refuse, crop rotation, balanced soil fertility, corn cribs well designed for natural drying, and use of hot air drying methods when the ears have an unusually high water content.

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