Corn Diseases In Illinois

Their Extent, Nature, and Control

By Benjamin Koehler
and James R. Holbert

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By BENJAMIN KOEHLER and JAMES R. HOLBERT[1]

CORN is the major farm crop in Illinois. The area devoted to it in this state during the last five years has averaged approximately 8,700,000 acres a year. This is more than the combined acreage devoted to oats, wheat, and barley. Furthermore the cash value of the corn crop is practically twice that of the combined value of the small grain crops just mentioned. Unfortunately corn also holds very nearly first rank in the number of diseases that attack it and in the losses caused thereby. Some of the diseases have as yet received little study. Many of them cause injury of such a nature that losses to yield of grain are very hard to estimate. In a bulletin published by the Illinois Station in 1924,[46*] it was stated that all the diseases besetting the corn crop in Illinois cause an average annual loss of at least twenty percent. In the light of further investigations this figure appears to be a very conservative estimate.

Some corn diseases are very conspicuous. Every corn grower is well acquainted with the ear rots and smut. He usually considers these as inevitable. There is a considerable number of other equally important diseases that weaken the plant and reduce the yield but cause no conspicuous external symptoms. Such diseases have, for the most part, escaped the grower's notice.

The material in this bulletin is designed especially to give the agricultural teacher and student, the farm adviser, and the interested farmer specific information concerning the extent and nature of corn diseases in this state, how they may be recognized, and how they may be held in check in so far as practical control measures are known. While it is impossible at the present time, even experimentally, to grow corn plants in any number to maturity free from disease, an important saving by partial disease control is available to all. Probably present losses could be cut in half by the application of methods already developed and known to be effective.

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*These figures refer to literature citations on pages 155 to 159.

The information presented here concerns dent corn principally, tho in general the same diseases occur on all the different kinds of maize, or Indian corn (*Zea mays*), namely, sweet, pop, flint, and flour corn, sweet corn usually being the most susceptible.

Effort has been made to present the discussions in simple language. Nevertheless, for the sake of accuracy and brevity, certain technical terms have to be used. The meanings of such words are explained in the glossary at the end of the publication. Each topic has been organized as a more or less independent unit. While this arrangement has necessitated some slight repetition between sections, the advantage to the reader is obvious. Facts concerning the behavior of corn diseases on the germinator are concentrated in the last part of the bulletin.

The authors have drawn freely upon material published by other investigators as well as upon their own experiences and observations. Literature references are given for some of the most important of these contributions, especially to the relatively recent ones.

NATURE OF PLANT DISEASES

Plant diseases are abnormal or unhealthy conditions of the plant or any of its parts that interfere with the natural functions or development. Such conditions may be brought about chiefly by: (1) fungous infection; (2) bacterial infection; (3) virus infection; (4) insect infection or poisoning; or (5) unfavorable environmental conditions. There are still other causes, but those mentioned have been found to be responsible for corn diseases.

Fungous Infection. Fungi cause the greatest number of known corn diseases. A large number of fungi (Fig. 1) resemble weeds in some respects in that they have organs corresponding to stems (aerial hyphae and conidiophores), roots (submerged hyphae and rhizoids), and seeds (spores). The outstanding difference between fungi and weeds is that the fungi have no leaves or green tissue, and therefore they cannot live independently as green plants can but must obtain their food from organic matter, dead or alive, just as animals do. When they attack live plants, they usually cause disease. Fortunately only relatively few of the two hundred thousand odd species of existing fungi are parasitic. Most of them are limited to dead organic matter for their food.

Some fungi can be seen only with a microscope, while others, as for instance the fungi (molds) causing corn ear rots, can be seen with the naked eye. Many of the fungi that attack live plants,

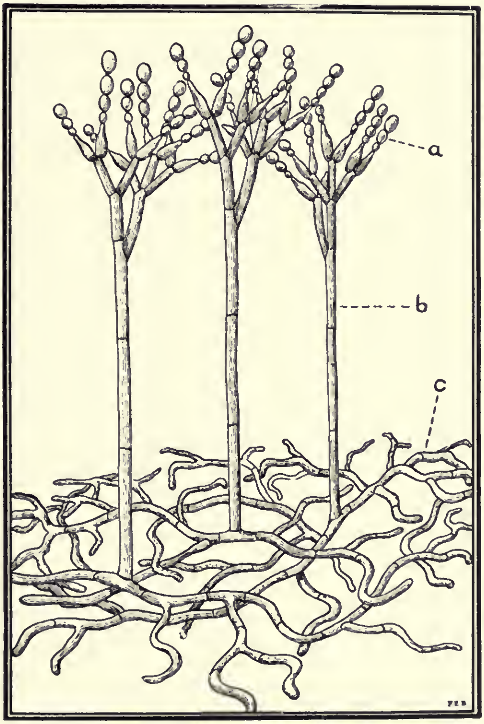


FIG. 1.—A FUNGUS PLANT, PENICILLIUM, GREATLY ENLARGED, ILLUSTRATING THE VARIOUS PARTS: (*a*) SPORES OR CONIDIA, (*b*) CONIDIOPHORES, (*c*) MYCELIUM. (Semidiagrammatic)

In a typical Penicillium colony there are many more stalks than here shown and each stalk has more branches and bears more spores. To the naked eye the whole colony looks like a dusty, felty mass. There are many kinds of fungi. The differences they exhibit may be just as great as differences in the higher plants, for example, those between the dandelion and the oak.

such as *Ustilago zeae* (one of the smut fungi of corn), are able to attack only the one crop, in this case corn. On the other hand, *Gibberella saubinetii* attacks not only corn but a number of other cereal crops also. Most of the fungi that attack live plants will grow also on suitable dead organic matter, but some others, such as corn rust, will grow and produce their spores only on live plants.

Fungus spores develop in a variety of ways, depending on the species of fungus. One common type develops its spores out in the air free from any protection, as shown in Fig. 1. Another type produces its spores in sacs or capsules, as shown in Fig. 25. While an individual spore is invisible to the naked eye, the capsules containing the spores (sporangia, pycnidia, or perithecia) can usually be readily seen. The former type of spore production is best adapted for rapid spread of the fungus during the summer, while the latter in many cases is better adapted to carrying the fungus thru adverse conditions, such as winter weather, because the spores are protected. Some fungi produce both types of spores. There are wide variations in both these types of spore production, and there are still other types which will not classify under either of those just mentioned.

The spores of fungi are carried by the wind, drainage water, insects, larger animals, and farm implements. When dry, some of them will remain viable for many years. Most of the corn-disease fungi live from one season to the next in the old corn refuse left on the fields. In the following season they produce spores which are scattered broadcast by the wind and infect the new crop. Some others are able to live from year to year in the soil apart from the corn refuse. A number are also able to live over winter in the seed corn and cause seedling diseases when the seed is planted.

Bacterial Infection. Bacteria cause several diseases in corn. These are very simple organisms, being composed of only one cell, as shown in Fig. 2. They are so small that a high-powered microscope is necessary in order to see them. The cells of bacteria that cause plant disease are, with few exceptions, all rod-shaped. In some species these rods have no provision for independent locomotion, while in others the rods are equipped with one or several hair-like growths by the movements of which the rod is able to swim about. Spherical and spiral shaped bacteria occur also, but most of these live only on dead organic matter. As is true in the case of fungi, most of the many species of bacteria are not parasitic, only certain species being troublesome in this respect.

Bacteria are carried from place to place and from one season to another much like the spores of fungi. Many of the parasitic species are able to attack only one particular species of plant. When they come in contact with the right plant and moisture and temperature conditions are favorable, some of these bacteria are able to enter the plant tissues thru the pores in the leaves. Other species of bacteria cannot do this so readily but are more dependent on plant injuries such as insect bites, frost cracks, etc., for gaining entrance to the plant tissues. Still others are carried over from one generation to the next in the seed. As these bacteria come in contact with water and the right food, they grow to mature size. Then

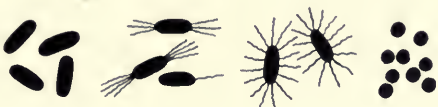


FIG. 2.—BACTERIA OF SEVERAL TYPES GREATLY ENLARGED
The many species of bacteria causing diseases may be placed in the four groups, or genera, shown above: (*a*) Aplanobacter; (*b*) Bacterium; (*c*) Bacillus; and (*d*) Micrococcus, according to Smith's classification. Only the first three, however, seem to be important as plant pathogens.

each cell divides into two, and each part again grows to mature size, and so on. In some cases such multiplication may occur as rapidly as several times an hour.

Virus Infection. There is a virus disease of corn known as corn mosaic. This disease occurs in the southern states, but has not yet been found in Illinois. The virus occurs in the plant sap, but cannot be seen with a microscope. There has been much conjecture about its nature. If a very minute portion of the sap from a diseased plant is injected into a healthy plant, the disease will develop as in the first plant. It can thus be carried from one plant to another indefinitely. This indicates that the causal agent in the sap is able to increase in quantity and thus seems to be alive. On the other hand, there is a possibility that a virus is simply a chemical structure perhaps somewhat analogous to an enzyme. Many virus diseases of plants and animals are known. Studies of these diseases are under way at various institutions.

Insect Infection or Poisoning. When insects cause mechanical injury to plants, the condition is usually not considered as disease, but when such injury is accompanied by injurious malformations of the plants, or when the insect bites cause extensive physiological disturbances, then it seems evident that the plants must be considered diseased. In the latter case a toxin or poison appears to have been injected by the insect, for wilting or blighting may soon occur. Diseases caused by such toxins or poisons are known to occur in several kinds of plants, and it is probable that corn plants are affected by injuries of this kind. In the south Atlantic states injury to corn by the eel-worm (root knot) disease has been reported. A tiny worm, microscopic in size, bores into the roots. This causes a swelling and abnormal behavior of the roots and consequently reduces the growth above ground.

Physiological Disturbances. The normal physiological behavior of plants is sometimes interfered with by environmental factors. A small amount of foreign gas in the air, as for instance sulfur dioxid, will cause wilting and dying of leaves. The gases emanating from some industrial plants have sometimes been under suspicion and in some cases have no doubt caused serious trouble. Unbalanced soil fertility may cause well-marked disease symptoms. On corn this is especially true in some parts of southern Illinois, where the addition of considerable nitrogenous fertilizer on the potash-deficient soil gives disastrous results. The ears in the latter case fail to mature and thus remain very chaffy. The stalks often are stunted and fall down early owing to unusual susceptibility to root and stalk rot under these conditions.

DISTRIBUTION OF CORN DISEASES IN ILLINOIS

All the diseases reported herein are, with a few exceptions known to occur thruout the state. Nevertheless differences in severity no doubt do occur with different geographical locations. For the most part accurate survey data on this feature are lacking, and where they are available they extend over only a few years. But a study of the regional influences that probably affect disease prevalence should be of value, and some of the factors will here be considered. It should be borne in mind, however, that all these factors interact on one another and that seldom is one factor alone responsible for a certain result.

Effect of Temperature. As the state of Illinois is nearly four hundred miles in length, the southern end is considerably warmer than the northern region. As winter temperatures are not of so much concern as summer temperatures in this discussion, the average temperature during the corn growing period only is mapped in Fig. 3. It will be seen that the average summer temperature in the southern group of counties is ten degrees higher than it is in the northeastern part of the state. Furthermore the data[94*] show that the temperature in the northern section is considerably more variable than in the southern section. The highest temperature recorded in

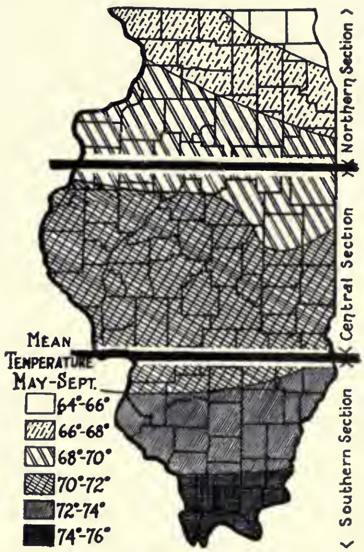


FIG. 3.—TEMPERATURE ZONES IN ILLINOIS, MAY TO SEPTEMBER INCLUSIVE

The warmer temperatures in the southern half of the state encourage the development of certain diseases which are comparatively rare or even unknown in the northern section. Some other diseases are not influenced in that way. (Sections indicated by heavy lines established by the U. S. Weather Bureau. Temperature areas plotted from U. S. Weather Bureau data.[95*])

the former is 112° F. while the highest in the latter is 115° F., a difference of only 3 degrees. There are periods when the maximum daily temperature in the north is just as high as in the south, but in the northern sections the nights usually are cooler and the warm periods are irregular, being more or less interspersed with cool periods. In the southern section the weather is more nearly constantly warm.

Several diseases are known to be influenced by these differences in temperature, and no doubt there are still others that also are influenced. The "brown spot" disease (page 103) causes considerable loss in the southern states but diminishes in importance northward, the northern limit of its distribution being somewhere in the neighborhood of the northern boundary of Illinois. Within Illinois it has been noted to be of greater prevalence in the southern than in the northern part. Warm moist weather is necessary for infection to take place.

Bacterial stalk rot (page 94) is another disease that is prevalent in the South, but has been observed no farther north than central Illinois. Like the brown spot disease, it too requires very warm moist weather in order to become established.

The black bundle disease has been observed to be more prevalent in the southern and central sections of the state than in the

TABLE 1.—PERCENTAGE OF INFECTED KERNELS IN ILLINOIS UTILITY SHOW CORN

(Five-year average, 1925 to 1929, of all yellow and white 10-ear entries at the State Utility Corn Show, Urbana)

Kind of corn	Disease infection	Northern[1] section	Central[1] section	Southern[1] section
		perct.	*perct.*	*perct.*
Yellow	Scutellum rot	8.12	9.33	10.40
	Diplodia zeae	1.95	1.68	2.18
	Gibberella saubinetii	1.49	1.13	1.56
	Fusarium moniliforme	9.01	9.24	14.52
	Cephalosporium acremonium	6.63	8.59	5.68
White	Scutellum rot	10.39	12.42	15.13
	Diplodia zeae	2.47	1.95	2.97
	Gibberella saubinetii	2.36	.95	2.16
	Fusarium moniliforme	8.43	12.36	15.02
	Cephalosporium acremonium	3.98	4.48	5.02

[1]See map, Fig. 3.

northern. It is not known whether or not this is due to differences in temperature. During two years the Illinois State Natural History Survey (page 78) obtained data on the prevalence of this disease in a manner that fairly represents the whole state. Their data for 1924 showed 2.8 percent diseased plants in the northern, 6.8 in the central, and 5.3 in the southern section, and for 1926 1.2, 3.4, and 5.9 percent respectively. Data secured from entries at the State Utility Corn Show over a period of five years, in an entirely different manner, corroborate these findings (Table 1). The ears entered in this show from the central section of the state carried a higher percentage of Cephalosporium than those from the northern section, in both yellow and white corn. In yellow corn the percentage of infection decreased in the southern section, but in white corn it increased still further over what it was in the central section.

Another important consideration in connection with temperature is the duration of the frost-free period. Maps illustrating the average time of the last recorded frost in spring and first recorded frost in fall are shown in Fig. 4. It is obvious that the season is shortest in the northern part of the state. This means that a shorter season corn is necessary there than is used in the central or southern

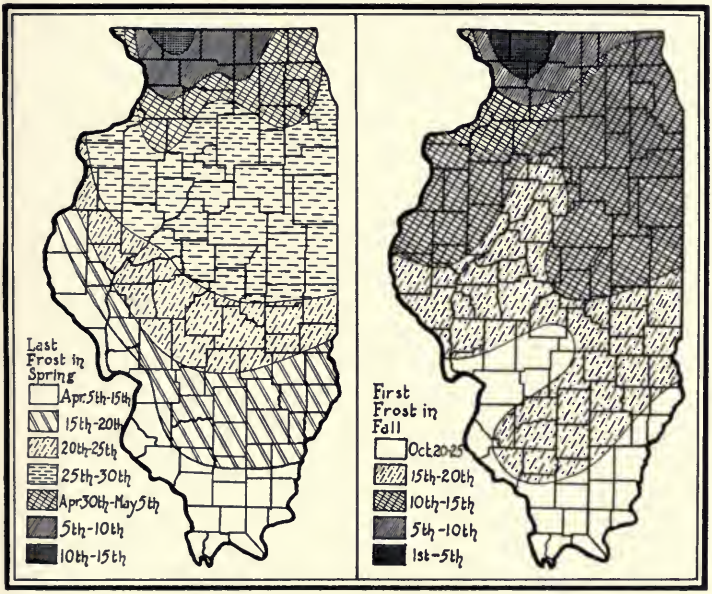


FIG. 4.—AVERAGE DATES OF KILLING FROST IN ILLINOIS AS REPORTED BY COLLABORATORS OF THE U. S. WEATHER BUREAU[94]*

Because the length of the growing season varies in different parts of the state, the corn types adapted to these different sections show many variations, among which appears to be their ability to resist certain diseases. The types grown in the shorter season of the northern section have been found to be more resistant to scutellum rot and *Fusarium moniliforme* ear infection.

part of the state. In how far the difference in length of season actually is a factor affecting prevalence of disease is not known. The fact that different varieties are used in the areas of different frost-free periods no doubt has some influence on disease prevalence, as will be discussed under corn types. Furthermore, as there is a greater tendency to plant in cold soil in the northern section on account of the shorter season, there would consequently be more trouble from certain seedling diseases, especially if the seed is not treated. The weather data on killing frosts as plotted in Fig. 4 are based on reports up to 1921 made by collaborators of the U. S. Weather Bureau.[94*] In general it may be expected that the growing season for corn is not so long as here indicated.

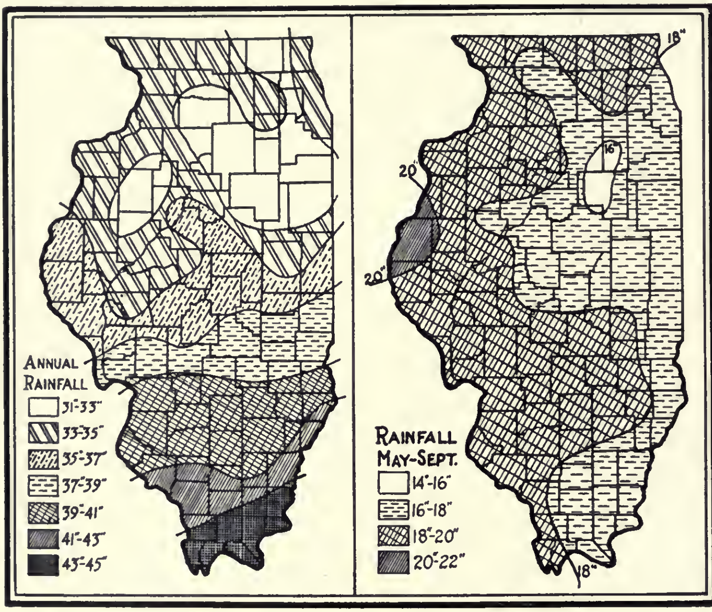


FIG. 5.—SUMMER RAINFALL, MAY TO SEPTEMBER INCLUSIVE, AS COMPARED WITH ANNUAL RAINFALL

The amount of annual rainfall increases progressively from the northern section of the state to the southern extremity. In summer, however, when the corn makes its principal growth, the rainfall is lightest in the eastern and heaviest in the western region. (Plotted from U. S. Weather Bureau data.[95*])

In many parts of the southern half of the state another factor enters. Owing to certain soil conditions the limiting factor in the spring is not frost but rather the soil moisture. Many farmers there begin planting corn later than those in the central section because the soil is too wet to start earlier. In that case only the additional length of the season in fall is of consequence. Furthermore the soil is fairly warm by the time the farmers are able to plant, so that they would be expected to have less trouble with seedling diseases if it were not for the high soil moisture which more or less counteracts the favorable temperature.

Effect of Moisture. High atmospheric moisture and also high soil moisture favor the development of many diseases. It is well known that the amount of annual rainfall increases from the northern to the southern part of the state (Fig. 5). But in a study of diseases on the growing corn plant we are concerned primarily with summer rainfall. Therefore the May to September rainfall was mapped and it was found that in the summer the rainfall is heaviest in the western region and lightest along the eastern region, as shown in Fig. 5. The heavy annual rainfall in the southern section is due largely to the large amount of precipitation occurring in that region from October to April. Among the diseases favored by high moisture are some of the seedling diseases, stalk rots, and ear rots.

Atmospheric moisture conditions during the fall also are of considerable importance in determining the final quality of grain produced. After the ears are mature or after the plants have been killed by cold, the quicker the ears become dry the less rot is apt to occur. When it rains much of the time during the fall months, especially when the rain is accompanied by mild temperature, severe losses from ear rots in the field or in newly cribbed corn are likely to take place. Danger of such losses are greatest in the southern section of the state, for, as shown in Fig. 6, the rainfall in that section during the fall is considerably greater than in the central or northern sections, the northern section having the lowest rainfall of all during that time.

Among the diseases that are favored by high moisture are some of the ear rots, stalk rots, and seedling diseases.

Effect of Corn Types. A state corn show,[71*] sponsored by the Illinois Crop Improvement Association in cooperation with the University of Illinois, has been held annually during the past eight years. A germination test has been made of every ear entered, and during the last five years data on all diseases occurring in this corn, as observed on the germinator, have been recorded as accurately as possible. Altho the percentages of disease infection in this show corn were no doubt considerably lower than occur in average farm seed corn, yet the data supply a basis for comparing the relative extent of seed infection in different parts of the state. It will be seen from Table 1 that the percentage of scutellum rot and *Fu-*

sarium moniliforme increases progressively from the northern section to the southern section in both yellow and white corn. This

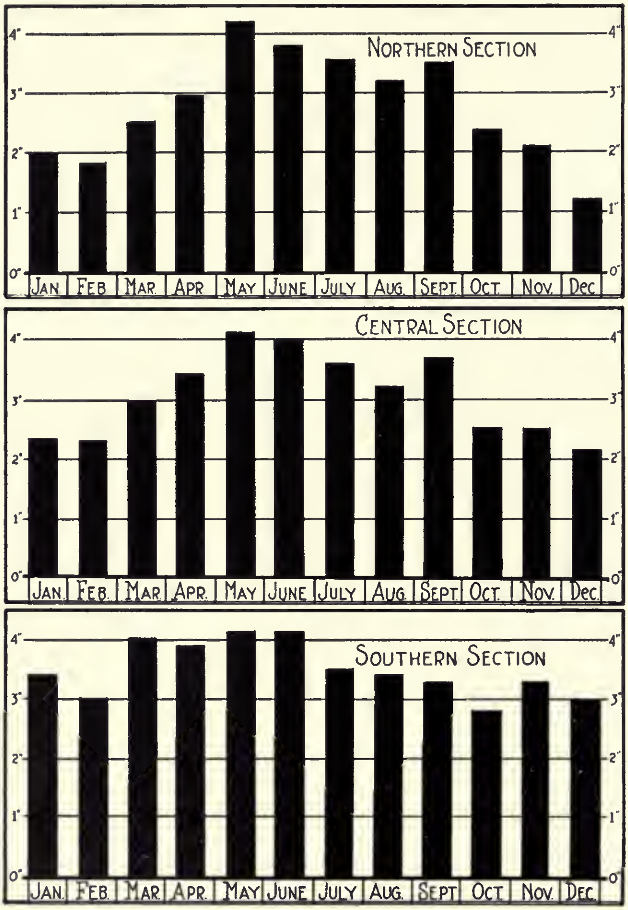


FIG. 6.—MONTHLY RAINFALL IN THREE SECTIONS OF ILLINOIS

The northern section has a favorable fall for the ripening and drying of corn. Heavy rains in the winter and early spring in the southern section cause corn planting to be delayed too long for best results, and when it is planted the soil moisture often is still high, a condition which encourages seedling diseases. (Plotted from U. S. Weather Bureau data.[95*])

difference seems to be due to the fact that altho all the corn in this show was, in one sense, of the utility type, the earlier-maturing corn from the northern region is more horny in composition than that to the southward, which has a longer growing period. In average farm seed corn the difference would probably be still greater than in the show corn from which these data were taken.

FIG. 7.—CORN ACREAGE, 1928, EACH DOT REPRESENTING 5,000 ACRES
The more extensively corn is cropped, the more prevalent and destructive most of the corn diseases tend to become. Corn is not so extensively grown in the southern third of the state as in the northern two-thirds, but still no county has less than 15,000 acres in corn. (Data taken from Circ. 385, Illinois Crop and Livestock Statistics, U. S. Dept. Agr. and Ill. Dept. Agr. cooperating.)

In these show exhibits the white corn proved more susceptible to seedling injury by scutellum rot and *Diplodia zeae* infection than the yellow corn. In the case of Cephalosporium (black bundle disease) the situation was reversed, except that here an error may possibly have crept in because Cephalosporium infection is sometimes more difficult to detect on kernels of white corn on the germinator than on yellow corn.

Effect of Intensity of Cropping. Other factors being similar, one would expect the most damage from corn diseases in areas where corn is cropped most intensively. Altho corn root rots, apart from the seedling diseases, have as yet received little study in this state, especially from the standpoint of their distribution, judging from what is known about soil-borne diseases of some other plants, the intensity of cropping is an important factor in determining the amount of damage caused by these diseases.

On account of the lighter cropping of corn in the southern third of Illinois (Fig. 7), there should be less corn refuse from the previous crops scattered about, and consequently one might expect less prevalence of certain diseases that are caused by wind-blown spores produced on old diseased refuse. Ear infection or ear rot is caused in this way. But apparently some other factors are active in counteracting such an effect, for Table 1 shows no such relationship. The warm, moist fall weather probably is a factor especially conducive to ear infection in this region.

METHODS OF DISEASE CONTROL

Not all diseases can be controlled in the same way, but a considerable number of corn diseases can be kept in check by the application of the same general methods of attack. These methods will be considered here in detail, so that a full discussion will not be necessary in connection with each specific disease. While ordinarily no one disease appears sufficiently destructive to warrant extensive applications of control measures, it is a fact that careful attention to a well-rounded program of control involving sanitation, crop rotation, soil management, breeding for disease resistance, plant and ear selection, seed treatments and, where feasible, a germination test, tends to check most of the major diseases, so that general control practices as set forth under the following headings are well worth while.

SANITATION

By sanitary measures are meant such practices as tend to eliminate germs, spores, or other inocula that cause disease. As yet such measures are not employed to a great extent for the control of cereal diseases, but it is thought that many diseases could be held in check by such practices, especially if carried out over a wide territory. In the case of corn the complete removal or turning under of all cornstalks and rotten ears before the new season opens would no doubt be a great help in reducing corn ear rots. These diseases are caused by spores produced on the old corn refuse and carried by the air currents to the new crop. Thoro plowing may also be expected to reduce smut and some other diseases. When the old refuse is covered with soil, the disease-producing spores cannot get out into the air to infect the stalks and ears of the new crop. One difficulty about turning corn refuse under is that of keeping it actually under the soil surface. When some of the undecayed stalks or ears are returned to the surface by the next year's plowing, there may possibly still be danger of this being a source of inoculum, altho the danger probably is not great. The application of this measure, even tho it cannot be carried out perfectly, promises to be of considerable help.

When corn fodder or ears are fed, the diseases are likely to persist in the unconsumed stalks and cobs. When these are thrown into the manure, the same precautions about thoroly plowing them under ought to be observed. Unless turned under well, such manure should not be used where corn is to be planted that same year. As for the spores that are eaten, it has been shown that smut spores which have passed thru the digestive tracts of cows or horses, no longer are viable.[28*]

CROP ROTATION

A number of the organisms that cause corn diseases are able to live in the soil or on the soil surface for some time. Some of them are dependent on the presence of corn refuse. As soon as the corn refuse has decayed, these organisms seem to disappear. Some others are not dependent on corn refuse. One of these is smut. Under outdoor conditions it does not seem to live on or in the soil longer than one year. The smut spores cannot serve as inoculum when buried beneath the surface. Pythium possibly also persists in the soil in the absence of corn refuse, but this fungus has as yet received little study. Many observations leave no doubt that root rots are considerably aggravated by cropping corn on the same soil very frequently. It is believed that a rotation including corn only once in three or four years would be satisfactory from the standpoint of disease control. This allows sufficient time for the old corn refuse to decay. It has been demonstrated fairly satisfactorily that corn plants are much more firmly rooted in such a rotation than where corn is cropped more frequently.[68*] Ear rots have been reduced by the same practice. Very likely some other diseases also are held in check thereby to some extent. Under certain conditions, however, there may be other important considerations which make such a rotation impractical.

SOIL MANAGEMENT

Nutritional factors not only have a large influence on vigor of growth and yield of corn grain, but they also influence the prevalence of diseases and the extent of the losses caused by them. Altho the relation of soil fertility to disease is not yet well understood, several general statements can be made.

A high state of soil fertility hastens the development and maturity of corn. There is evidence to show that, other things being equal, corn ears are drier in the fall when they have been grown on soil of good productivity than when grown on less-fertile soil, and in some seasons the differences are striking. Ears with low moisture content are less likely to develop ear infections and ear rots in the field during the fall. Unless the moisture is low at husking time, ear rot is likely to develop in storage.

While, as stated above, it is generally true that corn ears are drier in the fall when grown on soil of good productivity, the reverse sometimes is true. Temperatures that do but little damage to corn growing on more-fertile soil sometimes kill corn growing on poor soil; and while ears produced on poor soil may be highest in moisture at the time the plants are killed, after this event they dry out more rapidly than do the ears on the better soil, where the plans are still functioning. When harvested later in the season, the ears from the plants killed early will have less moisture than those from the more vigorous plants that grew to better maturity.

A lack of balance in the supply of plant-food materials may be a still greater handicap in the development of healthy corn plants than a low general level of fertility. The presence of a liberal supply of nitrogen, for instance, when the amount of phosphorus or potassium, or both, is inadequate, is especially conducive to the development of certain diseases. With respect to phosphorus it has been shown that a lack of this element retards maturity, and consequently where phosphorus is low there is more likelihood of injury from ear rot. The phosphorus supply, it has been shown also, is a factor in determining the importance of seed infection with *Fusarium moniliforme*. In experiments where rock phosphate was applied, seed infection with this fungus has been found to be of less consequence to yield of grain than it was in the check plots that received no phosphate.[46*]

An insufficient supply of potassium in relation to other plant-food materials also hinders proper maturation and thus increases the ear-rot hazard. When the potassium shortage is extreme, severe pathological conditions are likely to develop. Under some conditions the ears fail to develop properly and often dry out early in a loose, chaffy condition. This effect may be due in part to toxic conditions in the plant, and it may also result from failure of the plant to synthesize carbohydrates properly. Under some other conditions a lack of potassium may result in extensive root rot and sometimes also stalk rot, so that the plants remain stunted and fall to the ground during the latter part of the summer. A further discussion of this condition will be found under "Malnutritional Root Rot," page 93.

The application of agricultural limestone appears to be of considerable importance in correcting certain unfavorable conditions that sometimes occur in poorly drained soil that has an acid reaction and perhaps sometimes in other sour soils also. Limestone seems to convert the toxic substances to an insoluble or an inactive condition in which they are harmless. Very frequently liming causes the corn plants to stand up better than they do on similar land that is unlimed.[68*] The exact cause of this phenomenon has not been ascertained.

There are indications that variations in the nutritional balance have a bearing on the occurrence or the severity of still other corn diseases than those mentioned, but there is not yet sufficient evidence available on this point to warrant a definite statement.

In addition to the fertility of the soil, proper soil drainage and tillage also are of importance from the standpoint of disease control.

While the various aspects of soil management that have been mentioned deserve careful attention, it must be emphasized that soil management is only one of the corner stones for disease control. In fact there are some corn diseases that seem to be aggravated by *good fertility, as, for instance, smut and some stalk rot diseases. That some seedling diseases are very active in highly productive soil is indicated by the fact that when the corn is grown on such land, seed treatments nearly always give the best increases in yield. Thus it is only when a well-rounded program for corn improvement is followed that satisfactory results are obtained.*

DEVELOPING DISEASE-RESISTANT STRAINS

There is practically no evidence that any strains of corn are immune from any of the well-known corn diseases. Various strains and selections, however, grown under the same environmental conditions, may be damaged to widely different degrees by some diseases. Such differences, when due to the nature of the plants themselves, are called differences in *resistance* or *susceptibility.* The fact that there are certain hereditary differences in strains of corn and in individual corn plants, in their resistance or susceptibility to disease, is highly important from the standpoint of disease control.

The term *disease resistance,* however, must be clearly distinguished from *disease escape.* To illustrate: Corn grown where much of the debris of a previous corn crop has been left on the ground may show more ear rot than where corn of the same strain has followed a legume. This difference may be due to the presence of fewer spores of ear rot pathogens under the latter circumstances. This is an example of *disease escape.* Sanitation, crop rotation, and soil conditions, already discussed, are all concerned with disease escape, as are also soil temperature, soil moisture, and certain other factors. *Immunity* from a disease means complete absence of disease under all the natural conditions under which the plant may be grown, even where the pathogen is present and the environmental conditions are favorable for disease development. But, as stated above, immunity of corn to any of the well-known corn diseases probably does not exist, altho marked progress has been made in developing highly resistant strains, as discussed later.

In order to obtain the highest yields and best quality of corn, it is well for the corn grower to use such practices as will permit the corn to escape disease so far as possible. When breeding for better disease resistance, however, it is necessary to use measures that are in some respects completely opposite to those that are recommended for growing the most profitable commercial crop.

Selections should be made from corn which has been thoroly exposed to the diseases in the field and has proved resistant. A plant that has simply escaped disease may appear to be healthy and the ear from it may test free from disease on the germinator, and yet when the progeny of this plant is exposed to infection, the plants may become badly diseased. In other words, a disease-free ear will not necessarily produce healthy plants; the ear may be free from disease only because it has not been exposed to infection and not because it is resistant to infection.

The fundamental considerations for the development of disease resistance in corn are essentially the same whether open-pollinated or inbred strains are used.

Open-Pollinated Strains. Strains of corn grown on a commercial scale at the present time are with few exceptions all open-pollinated. Cross-pollination is the natural process in corn. This is altered only when artificially controlled by man. In certain cases studied it was found that only 5 percent or less[34, 62, 112*] of the kernels on an ear were self-pollinated, that is, fertilized by pollen from the plant that developed the ear. The other kernels were fertilized by pollen from other plants. Pollen may be effective even after having been blown half a mile away. Cross-fertilization makes it more difficult to obtain and maintain disease-resistant strains. Being cross-pollinated, the ears that are selected will not breed true for the characters desired, and therefore selection must be kept up year after year. Thus selection toward better disease resistance is slow work but, nevertheless, considerable improvement can be and has been made.

There are many named strains of open-pollinated corn on the market, but these names in themselves mean nothing with respect to disease resistance. The worth of a strain of corn can be estimated only when it is known with what ideals and care the strain was selected up to the time it was received. At the present time in Illinois the so-called "utility type" is more generally used, but still many farmers do their selection in a superficial manner and fail to take into consideration the various characters that tend to indicate disease resistance and freedom from disease.

The term "utility type" has been adopted very generally thruout Illinois to designate any open-pollinated variety of corn that has been selected with particular reference to disease resistance of

FIG. 8.—UTILITY EAR TYPES

Some of the important characteristics of utility ears are: good length, medium diameter, heavy weight in proportion to size, medium-smooth indentation, bright luster, horny kernel composition, a shank attachment that breaks off smoothly and is free from rot, freedom from weathering and mold, and plump, bright kernels with well-developed germs.

the plant and ear and to inherent capacity to produce satisfactory yields of sound grain irrespective of whether or not the ears conformed to any other standards such as straightness of the rows of kernels and uniformity of size and shape of ears.

In Illinois this term had its origin about the time and in connection with the first State Utility Corn Show in 1921. The corn at this show was judged by what was then a new score card. The points on this score card and their relative weights represented the composite judgment of workers in the University of Illinois, the U. S. Department of Agriculture and, in addition, many corn breeders and corn growers. It was the aim of those workers to formulate a score card that would call attention to and emphasize the physical characteristics that experimental evidence had shown to be associated, to a considerable extent, with disease resistance, better seed condition, and higher yields of sound corn. The score card included a germination test. This score card soon became known as the "Utility Score Card." Corn selected according to the standard set up in this score card is known as "utility type" corn (Fig. 8).

Later this score card was modified somewhat and adopted by the Illinois Crop Improvement Association as the official score card for the Annual State Utility Corn Show.[71*] Since that time other corn score cards involving somewhat similar ideas have been suggested and in a few cases adopted by corn investigators of some other states. A good score card in which important ear and kernel characteristics are considered but in which the germination test is omitted has been proposed by Hughes and Robinson[50*] of Iowa.

It may be pointed out here that there is considerable difference between "utility type show corn" and "utility type seed corn." Altho the former is the offspring of the latter, a number of the old corn show ideas have been retained (wisely or unwisely), so that considerable weight is given to uniformity and other characters which have little or no commercial value.

Crosses of Inbred Strains. The U. S. Department of Agriculture, many of the state agricultural experiment stations, and a number of private corn growers' and business organizations are developing inbred strains of corn. A number of crosses between such inbred lines have proved highly resistant to some diseases (Fig. 54) as well as highly productive. There is much hope that superior crosses will be obtained that will be resistant to all the more important diseases as well as highly desirable from other standpoints. Single- and double-crossed seed from inbred lines, which is superior to open-pollinated seed in quantity and quality of grain which it produces when grown under certain climatic and soil conditions, is already available from some seed houses. Progress apparently is being made yearly in the production of better inbred strains and crosses, and it seems likely that seed of these better crosses will be used to a considerable extent in the future. This method of breeding is still in the experimental stage, however, and many difficulties are still to be overcome. From the standpoint of developing disease-resistant strains by this method, the following considerations may be mentioned:

1. Resistance to the many corn diseases depends on many characters, both structural and functional. Inbreds that are resistant to one or several diseases have already been obtained, but resistance to a greater number or to all of the more important diseases is desired.

2. The fact that there are different strains of pathogenic organisms increases the difficulty of breeding for disease resistance. It was found[7, 102*] that some inbred lines of corn that had been highly resistant to smut became very susceptible when a smut culture was introduced from another region. Physiologic strains are known to occur not only in corn smut but also in corn rust.[75, 102*] They may occur also in some other corn pathogens. Considerable variation is known to occur in the cultural behavior of various isolations of *Fusarium moniliforme* and *Gibberella saubinetii*. In how far these fungi exhibit physiologic specializations in their activities as pathogens has not been adequately studied.

3. For the best results different crosses will probably have to be produced for different environmental conditions. Thus if a strain is developed that is highly resistant to most diseases, its use will likely be limited to restricted areas having similar soil and atmospheric environment, and other strains must be produced for other regions. What the ultimate size-limit of an area will be for a given strain cannot be predicted, but it probably will not be greater than, for instance, an area best adapted to a single strain of wheat and it may be considerably smaller.

SELECTING DISEASE-RESISTANT AND NEARLY DISEASE-FREE SEED[a]

Plant Selection. Given a strain of corn well adapted to local conditions, the first important consideration in the selection of

[a]The word "seed" is here used in its popular sense rather than in its exact botanical meaning.

disease-resistant and nearly disease-free seed is the selection of plants that possess characters which we wish to propagate. Many important hereditary features, including resistance to certain diseases, or morphological weaknesses that allow disease organisms to enter, can be observed in the mother plant but not in the ear. Only after a satisfactory plant has been found should the ear be examined to see whether it too appears satisfactory. Not too much attention should be given to ear characters at this time, because that can be taken care of better after the ears have been cured. Unfortunately many farmers pay too much attention to type of ear when selecting corn in the field and take too little time in scrutinizing the plant from which it came. Altho corn is cross-pollinated and one can examine the mother plant only, still by careful selection year after year considerable progress can be made.

The corn should be allowed to mature well, in so far as weather conditions permit, before seed selections are made. The selections should be made before there is excessive damage from cold weather, altho a temperature just low enough to kill the leaves of plants more susceptible to cold injury, occurring before selections are made, may be of distinct advantage, for then selections can be made for resistance to cold injury as well as for resistance to disease. It should be borne in mind, however, that even tho immature plants usually are less subject to damage by low temperature than are the more mature plants, they should *not* be selected for seed purposes. When a plant is injured by low temperature, the leaves or the affected portions of them have a dull, pale bluish-green color, as if they had been scalded. If examination is made shortly after the injury occurs, such leaves can be clearly distinguished from those that have died earlier, but usually after a few days have elapsed the "frosted" leaves, or portions of them, turn straw color, and it is not so easy to discern the exact cause of their death. However, even after practically all the leaves have been killed by low temperature, considerable difference in the health of a plant and its resistance to cold is indicated by the greenness of the stalk and by its firmness when pressed between the fingers.

As husking by machinery is increasing in popularity, it becomes of greater importance than formerly to select strains that stand erect in the field until husking time. Selections for erect stalks can no doubt be made to best advantage late in the season, possibly in November (Fig. 9). Such late selections should be made in addition to those made earlier in the season and, for breeding purposes, the seed of these late selections should be planted separately from the earlier selections, for one cannot depend on getting good seed corn so late in the season every year. A breeding project

FIG. 9.—RESISTANCE TO STALK BREAKING IS INHERITED

Two inbred lines of corn as they appeared at harvest time are shown above. The one on the left is very susceptible to stalk breaking, every ear usually being on the ground by the first week of November. The one on the right for the most part remains erect thruout the winter. Continuous selection in open-pollinated strains is also effective in increasing the tendency of corn to stand erect until husking time.

cannot be completed in one year, and it will be necessary to reselect for stiff stalks every season in which weather conditions are favorable.

Plant selection is of value only in proportion to the care and intelligence exercised in making it.

Important Points in Making Plant Selections

1. The plants should be well anchored by the roots; they should stand erect. Plants that lean over are likely to have either considerable root rot or a weak root system. It is undesirable to propagate the tendency toward either one of these defects.

2. The stalk and parts of the leaves should be green while the husks have turned straw color. Plants showing firing or dying of the leaves or any considerable reddish or purplish discoloration of leaves or stem, or plants severely injured by low temperatures should be avoided. Some of these conditions may be an indication of disease (Plate I) or may be associated with susceptibility to disease.

3. The plants should be free from smut. Susceptibility to this disease is inherited.

4. The ear should be supported by a sturdy, unbroken shank. Broken shanks frequently are diseased and the infection may extend into the ear.

5. It is of some advantage to have the shank so curved that the tip of the ear is inclined downward. Then the water will run off the husks as from the shingles of a roof. Less infection has been found in such ears than in those that stand upward. Care must be taken to see that they are inclined in natural growth and not because the shank is broken.

6. The husks should cover the ear well. This reduces the chances for ear infection. In some fields it is difficult to find well-covered ears. After several years of careful selection for long husks, it no longer becomes so hard to find them (Fig. 10).

7. The ears themselves should not be very large in circumference, as such ears dry slowly and therefore are open to disease infection for a longer period. Ears showing mold or insect injury should not be taken, for they would be culled out later.

There are still other characters in type of plant and type of ear that the grower will want to consider, but as these are not directly concerned with disease resistance or the presence or absence of disease, they are not within the province of this publication.

Curing. After the seed ears have been selected they should be dried rapidly. Under some seasonal conditions when the corn is rather high in moisture and the weather conditions are not favorable for drying, proper drying facilities are a serious problem on the average farm. Under such conditions a heated and well-ventilated drying room is almost imperative. In some houses the room above the kitchen answers fairly well for this purpose. Hanging the corn in a shed is risky, for the disease molds spread rapidly in the damp ears and, furthermore, in case of a hard freeze the seed may be injured or killed. Some commercial equipment which assures forced ventilation at 100° to 110° F. seems very satisfactory. This temperature checks mold growth and is not hot enough to injure the seed. Under favorable seasonal conditions, on the other hand, there is no difficulty in curing the ears properly under ordinary farm conditions if good judgment is exercised.

Weak light is desirable in the drying and storage room. Bright

PLATE I

A Plant prematurely dead on account of disease.

B Plant maturing normally.

In the diseased plant (*A*) the leaves are either dying or already dead and the ear is hanging down as the result of a crumpled and rotted shank. Corn produced on such a plant is light or chaffy. While it is evident that such ears are not good for seed purposes, there are intermediate stages between *A* and *B* in which the ear may have a good appearance superficially and yet be physiologically immature and therefore produce plants very susceptible to disease.

In the healthy plant (*B*) the ear is maturing normally while the leaves and stalk are still green. Corn from such plants makes excellent material from which to select seed.


A
B

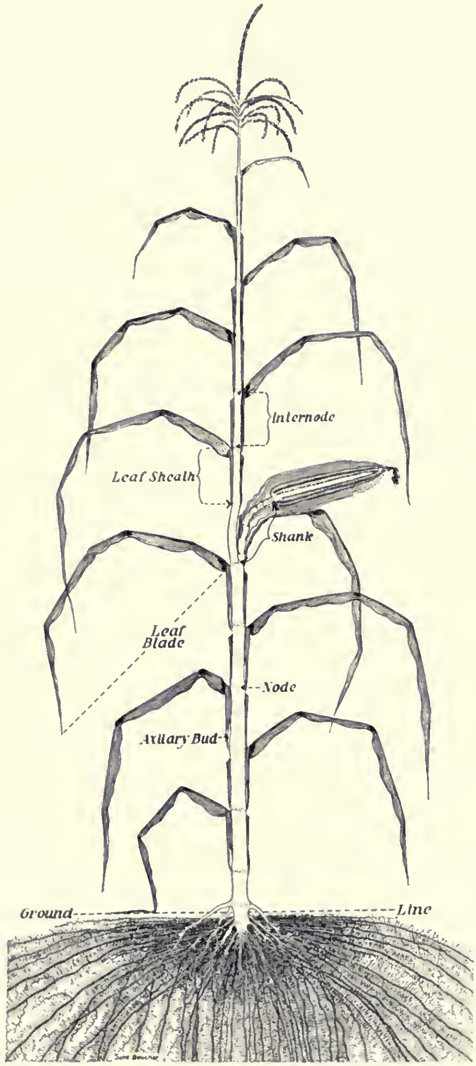


FIG. 10.—SCHEMATIC DRAWING SHOWING A LONGITUDINAL SECTION OF A CORN PLANT OF THE DENT VARIETY

Note the rudimentary buds in the leaf axils beneath the ear. These are weak points thru which infection of the stalk often takes place. Note also how the husk covers the shank and ears, protecting these parts against infection as well as cold injury during short periods of low temperature.

light, especially direct sunlight, bleaches the ears so that it is impossible to take the kernel luster into consideration when doing the final selecting. Hangers in which the ears are laid are preferable to those that have prongs on which the ears are stuck, for the shank attachment is taken into consideration when the ear is re-examined and therefore it should not be marred.

Ear Selection (physical). The seed ears should be selected with care and discrimination after they have been dried or cured.

Not every ear that is diseased or susceptible to disease can be detected and removed in this selecting or culling process, but by observing the following points the seed lot can be greatly improved. Points 1, 2, 3, 6, and 7, listed below, are concerned primarily with complete maturity of the ear. As disease infections, whether of the root, stalk, or ear, frequently arrest the final maturing stages, the completely matured ears are more likely to come from relatively disease-free plants.[46*] The new crop, when grown from such seed, will have greater resistance to certain diseases. Points 4, 5, and 8 are more directly concerned with disease symptoms.

Important Points in Making Ear Selections

1. The kernel indentation should not be very rough (Fig. 8). In addition to indicating immaturity and the probability of a high percentage of soft starch, the outer tips of the rough kernels usually become broken in handling and this also is undesirable (page 127).

2. The ear should be outstanding in weight and solidity. Some practice is required in order to estimate the comparative weights of ears with sufficient accuracy to be of value in making selections.

3. Good luster of the ear is highly desirable. This means a bright, polished, waxy finish regardless of color.

4. The whole ear, including the tip, should be free from all molds, weathering, and discolorations of every kind. Also the seed coats[a] of the kernels should not be broken, as they sometimes are, either from natural causes (Fig. 59), rough handlings, or mouse and insect activity (Fig. 61). Mouse damage may be confined to certain parts of the ear only, and if the ear is otherwise satisfactory, it may sometimes be saved by removing and discarding the injured kernels.

5. The butts should show a clean break of healthy tissue. Ears with shredded butts (Fig. 11), or those having yellowish or dull brownish discolorations, are especially to be avoided. Look for the presence of Basisporium spores (Fig. 12).

6. After the ear has been examined as a whole, a number of representative kernels should be removed for examination or, if no germination test

[a]Meaning pericarp; seed coat is used here in the popular sense rather than in its exact botanical meaning.

FIG. 11.—ONE GOOD (LEFT) AND TWO UNDESIRABLE SHANK ATTACHMENTS

A clean break of healthy tissue indicates that the shank was healthy and that probably no diseases have entered the ear by that route. A rotted or shredded shank attachment indicates a probability either that diseases have entered the ear at that place or that diseases or other unfavorable circumstances have caused the whole plant, or possibly only the shank, to die prematurely. The kernels of such ears are likely to carry infection, or at least may be susceptible to infection when planted.

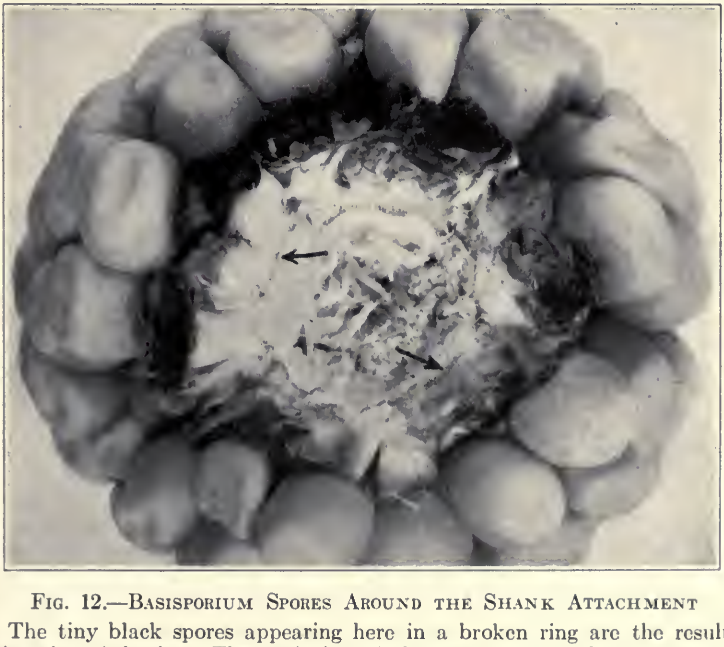


FIG. 12.—BASISPORIUM SPORES AROUND THE SHANK ATTACHMENT

The tiny black spores appearing here in a broken ring are the result of Basisporium infection. The majority of the kernels on such an ear are infected. The spores are often much more numerous than here shown. Ears with a sound shank attachment are not likely to show these fructifications.

is to be made, it is best to shell each ear individually after it has passed the tests just mentioned and then to thoroly examine the shelled kernels. There are two kinds of starch in the endosperm—hard horny starch, which has an amber-like appearance in yellow corn, and soft floury starch. The difference can be noted from the exterior of the kernel (Fig. 13), the horny being semi-translucent and the floury being opaque and, in yellow corn, lighter in color. Selection should be made for a high percentage of horny starch. Ears that pass the germination test should afterwards also be shelled individually and carefully reinspected for horniness as well as the following points:

7. The kernels should be well developed, carrying their full thickness to the point or tip of the grain (Fig. 14).

FIG. 13.—HORNY KERNELS OF CORN (A); FLOURY, OR STARCHY, KERNELS (B)

In good seed the horny, amber-like endosperm should extend down to the tip of the kernel and should extend up very nearly to the cap or dent. In dent corn, floury endosperm may be a varietal characteristic or it may be an indication of immaturity of the grain. Corn kernels with a marked degree of floury endosperm are usually undesirable for seed.

8. The kernels should be free from any streaks (Fig. 15), spores (Fig. 16), and whitish, grayish or brownish discolorations. The latter are especially apt to occur toward the tip end of the kernel.

9. Cracked seed coats may occur on the sides of the kernels, where they are not noticed until the ears are shelled (Fig. 17). Such ears should be discarded.

10. When the grain is shelled from the cob, in most corn belt varieties, the tip cap of the kernel should remain on the kernel and not on the cob. These tips breaking off may or may not be a sign of disease infection, but at any rate if they break off, the grain lacks this protection and is open to infection as soon as it is planted.

FIG. 14.—MATURE AND IMMATURE KERNELS IN THEIR NATURAL POSITIONS ON THE COB

Mature grains carry their full thickness down to the very tip of the kernel (left). Grains that have dried and hardened while still decidedly immature (right) are not filled out at the tip, altho there may be no indication of this condition in the unshelled ear. When shelled, the undeveloped condition at the tip of the kernels, together with lack of horny endosperm in this region, is easily recognized. This lack of development may be caused by disease or by the occurrence of low temperatures before the ear is mature.

FIG. 15.—ONE SOUND AND THREE INFECTED KERNELS

White streaks as here shown, as well as black streaks, are a good sign of fungous infection, and ears showing such a condition should not be taken for seed. A yellow or brown discoloration at the lower end of the germ is another indication of infection. By observing such signs as these and others described in the text, many undesirable ears can be eliminated from the seed lot. Even tho such ears appear free from disease in a germination test, yet field experiments have shown such seed to be inferior in performance.

FIG. 16.—KERNELS INFECTED WITH BASISPORIUM

The tiny black spores of this fungus are observable on four of the above kernels. They are not always abundant enough, however, to be readily noticed with the naked eye (Fig. 27). Many infected kernels show no spores at all.

FIG. 17.—SO-CALLED "SILK CUT" OF CORN

In the unshelled ear this kind of injury often is not noticeable. For the detection of this, as well as other kernel defects and discolorations, every ear should be shelled separately and the kernels carefully examined before deciding to use the ear for seed.

Germination Test. The germination test is a good basis for judging the fitness of an ear for seed purposes. When properly conducted, it should indicate two important factors—vigor of growth and presence or absence of certain diseases. The appearance of these diseases on the germinator is discussed later in this bulletin.

Instead of the germination test being the third step in seed-corn selection, many people have made it the principal consideration. This the writers feel is a mistake. Plant selection and ear selection take into consideration important characters associated with the development or maintenance of disease resistance, for which the germination test cannot be substituted. Most farmers are neither equipped nor properly trained for conducting the germination test most effectively. The construction and maintenance of a germinator is a problem in itself. Among other things, proper temperature, aeration, moisture of the substratum, and humidity of the atmosphere must be maintained in order to make the disease symptoms or signs visible and in order to get uniform results.

Altho a germination test may be necessary for best results, nevertheless if plant selection, ear selection, proper curing, and seed treatment are carefully practiced, the results in a normal year seem to be nearly as satisfactory as if the germination test for the elimination of diseased ears had been added to the measures just mentioned. People who are not very careful in plant selection and ear selection will get comparatively greater returns thru selection on the germinator, if it is properly done, but the results cannot be so satisfactory, especially in the long run, as they would be if these other selections had first been made. In short, now that good seed treatments are available, physical selections (plant and ear) would ordinarily appear to be of greater importance than the germination test, for resistance to certain diseases, some of them not seed borne, can be built up by physical selection while the germination test, as far as disease is concerned, gives information only on seed infection, which to a considerable extent can be remedied by seed treatment. In years when, owing to damage from freezing, there is question concerning the vigor and viability of seed corn, the germination test is essential.

SEED TREATMENT

Successful chemical treatments for seed corn are a new development. Even five years ago there was no treatment that could be recommended. Intensive investigations concerning the treatment of seed corn began only after organic mercury compounds had been introduced. Such a compound was used first in Germany for the control of bunt of wheat in about 1912. This compound, a chlorphenol-mercury, was later introduced into the United States and its application to corn in extensive field plots was probably first made in Illinois.[a] It gave considerable promise as compared with chemicals that had previously been tried. Soon a number of other organic mercury compounds of different chemical compositions were being manufactured, some good, some not so good. All these early compounds had decisive limitations, but manufacturing chemists had become keenly interested in the matter and more new compounds were produced. Altho most of these products were of little value, occasionally improvement was made, so that fairly reliable and effective seed disinfectants are now available. Several commercial seed disinfectants that can be recommended are on the market. These are patented materials and can be obtained only under their trade names. Other desirable and possibly superior products may be developed in the future, but of the many disinfectants so far tried, extremely few have been found to be highly desirable, and it is probable that some comparatively worthless compounds under various names will also be offered for sale to the public.

On the basis of experiments thus far made it may be concluded that the average farmer of the northern or central sections of Illinois (Fig. 3) under average conditions may be fairly confident of an increase of 2 or more bushels per acre in his yield of dent corn by applying a good seed treatment at an outlay of about three cents an acre for the disinfectant.[49, 79*] For the purpose of experimentation samples of corn were obtained from 285 farmers in central Illinois during the seasons 1928 and 1929. These were composited and grown under several different soil conditions. An average increase of about 3 bushels an acre was obtained (Fig. 18) as a result of seed treatment.

Under some conditions increases in stand, vigor, and yield of grain obtained from seed treatment have been very striking. Even with the very best seed obtainable, seed treatment, in Illinois experiments, has usually proved worth while. Ordinarily the differ-

[a]These experiments were started in 1923 by Chas. S. Reddy in cooperation with the authors of this bulletin.

ence in the growth of corn from treated and untreated seed cannot readily be detected by inspection but accurate yield determinations must be made in order for the difference to be evident.

Seed treatment is not, of course, a remedy against all corn diseases. The more noticeable diseases such as smut, ear rot, stalk rot, and root rot are not directly controlled by seed treatment

FIG. 18.—DIFFERENCES IN THE VEGETATIVE GROWTH OF DENT CORN CAUSED BY SEED TREATMENT

This striking difference in size occurred in 1929, when planting was followed by three weeks of cool, rainy weather. Ordinarily when fairly good seed is used, the effect of seed treatment cannot readily be detected until the husked corn is weighed.

altho some may be slightly checked indirectly because of the better vigor and the more advanced development of the plants from treated seed. The best seed disinfectants now available, however, are effective in the control of many seed borne infections. This fact has to a considerable extent reduced the importance of the germination test for the control of seedling diseases. Furthermore the treatments seem to offer some protection against infection from the soil. Much of the damage to the young corn seedlings seems to be caused by the so-called "saprophytes" or "weak parasites" which occur abundantly in the soil. The predominating types of these organisms no doubt vary greatly with different soils and with different crop sequences. When the soil is wet or cold or both, some of the "weak parasites" are especially prone to be harmful. Under some other conditions the same organisms may be practically harmless. Treated seed can be planted early with greater safety than untreated seed, for there is less danger of damage in case it should lie in the ground, because of unfavorable weather conditions, for a long time before sprouting.[49*] It has often been demonstrated

FIG. 19.—A SEED-TREATING MACHINE MADE FROM A STEEL OIL DRUM

One half of one of the drum heads is cut out and a tight-fitting hinged lid is put in its place. A shaft made of one-inch iron pipe is fastened in a diagonal position thru the drum. One or several baffle boards should be fastened on the inside. This size treats one bushel of seed at a time. It is suitable for all kinds of farm seeds.

that when seed of good quality from full-season varieties is used, the early-planted corn (May 1 for Urbana) usually yields the best.[69*] Altho seed treatments sometimes have proved of no benefit, yet in the event of unfavorable environmental conditions during the germinating period the treatments become highly beneficial and may even prevent the necessity of replanting. They have given enough return, on the average, to allow a good profit on the investment.

Seed treatment, it should be emphasized, is no substitute for good seed. Special attention should be given to physical selection; when well done, this is more important than seed treatment, but a good treatment may be worth while as an additional measure. In fact, farmers who have been giving careful attention to plant and ear selection for a number of years are in many cases getting more benefit from the use of a good seed disinfectant than are farmers who have spent comparatively little time in selecting their seed ears.

Some of the same treatments that have proved beneficial on dent corn, when applied to sweet-corn seed, have been found to cause a substantial increase in the yield of prime canning corn.[90, 91*]

As yet no seed-treatment experiments have been conducted under the soil and climatic conditions of the southern section of the state. Claims have been made by certain manufacturers that their disinfectants not only protect the corn seedlings against disease infection but that they also control insects which attack corn in the ground shortly after planting. The results of several years' tests in Illinois indicate that such is not the case.[120*]

The effective commercial seed disinfectants should be applied at the rate of 1½ to 2 ounces to a bushel of shelled corn by the use of a good mixing machine. Mixing the chemical dust with the grain by means of a shovel should not be attempted for three reasons: (1) a good coating of the seed cannot be obtained; (2) too much of the dust is lost in the air; and (3) the method is extremely dangerous to the health of the operator. A barrel churn does very well for small quantities, but should be filled only one-third full of grain. A good mixing machine, handling a bushel at a time, can be made of a 30-gallon metal oil drum (Fig. 19). A concrete mixer answers the purpose if a tight lid can be fixed over the opening. Various commercial mixers are on the market. Care should be taken to avoid inhaling the dust. The mixing should be done out of doors or on a barn floor with the doors open on both sides. Respirators that fit over the mouth and nose so as to protect the operator are low in price and can be purchased in some drug stores.

After the corn is treated it should be stored in a dry place. Leaving it in an open building where the humidity of the air is similar to what it is out of doors would likely be a risk under some weather conditions. Such exposure is not very apt to kill the seed but it may have a depressing effect on the vigor of the resulting crop and consequently on yields.

CAUSES OF DEAD SEED

A number of diseases of corn kernels may result in death of the embryo (germ). Usually such dead kernels show external discolorations to the extent that they can be recognized by the man who carefully selects his seed corn. There are two diseases, however, that sometimes kill without showing discolorations or other external symptoms. These are Diplodia and Gibberella. When external symptoms are lacking, infection with either of these diseases can be detected only by means of the germination test, which is described later in this bulletin.

Other common causes of dead kernels in corn of good appearance are cold, heat, and old age.

With respect to the effect of low temperatures, it is generally true that the higher the moisture of the grain the less cold it will stand without injury. Considerable difference exists, however, between individual ears and individual kernels in their resistance to cold at a given moisture content. The length of time during which a low temperature is maintained is a factor also. In experiments at the Nebraska Station[64*] it was found that the danger points for seed-corn injury from exposure for 24 hours to low temperatures occurred at approximately the following moisture-temperature combinations: 30 percent moisture, 28° F.; 25 percent moisture, 24° F.; 20 percent moisture, 16° F.; 17 percent moisture, 4° F. In any case an increase in moisture or a decrease in temperature sometimes caused considerable mortality. Somewhat lower temperatures proved safe when the time of the exposures was not so long. To just what extent these data are applicable to weather conditions in Illinois is not definitely known, but they doubtless may be taken as suggestive.

On the other hand, seed may be killed by having the heat too high during the curing process. Experiments by Harrison and Wright[32*] at the Wisconsin Station have shown that ear corn dried by forced warm-air ventilation at temperatures of 104° to 113° F. was not injured. Corn dried at a temperature of 122° F. was considerably injured. Those investigators found that ear corn could be dried to 12 percent moisture in 72 to 96 hours at temperatures of 104 to 113° F. without injury to germination, seedling growth, or field performance. These results are in accord with experience in Illinois.

Seed corn ultimately dies from old age. Under what environmental conditions and moisture content of grain it will live longest, and to what extent various disease infections affect longevity, have not yet been determined. It is well known that while old seed carried over for one year sometimes gives very good results, the vitality often is not so good after it has reached that age. The senior writer has stored nearly disease-free yellow dent seed corn of the horny type for five years, and at the end of that time found the germination perfect and vigor good. When planted in the field, the yields from such seed were very nearly the same as those from fresh seed. However, the quality of seed corn more than one year old is always to be questioned until satisfactory viability and vigor have been demonstrated by means of a germination test.

It is probable that occasionally dead grains may be the result of deficient or deleterious hereditary factors. In inbred corn dead grains are frequently found that cannot be explained by causes outside the plant itself.

SEEDLING DISEASES

GENERAL CONSIDERATIONS

There are a number of diseases of seedling corn plants that are very important. They result in poor stands, blighted plants, and weak plants.

In almost any planting many grains germinate and yet do not come to the soil surface. Often this is due to a rot or blight of the seedling before it emerges. On the other hand, under field conditions there may be some missing plants even where only the very best seed was used, for much depends on the physical condition of the soil. The young shoot has to push its way thru to the surface or perish, and the most vigorous seedlings may be obstructed by clods that cannot be penetrated. All the diseases considered here generally cause more or less loss of vigor. As the perfection of the field stand, under any given conditions, is in proportion to the degree of vigor of the seedlings, it is evident that diseased seed is very apt to cause a poorer stand than nearly disease-free seed, even tho the disease in question does not directly cause the death of the seedlings but only reduces their vigor.[46, 68*]

Some plants blight in the seedling stage even after they have made some growth above ground. They dry up and fall to the ground. After the first cultivation usually all trace of them is lost.

Perhaps the greatest damage caused by these seedling diseases is due not to the loss in stand or blighting of plants, but rather

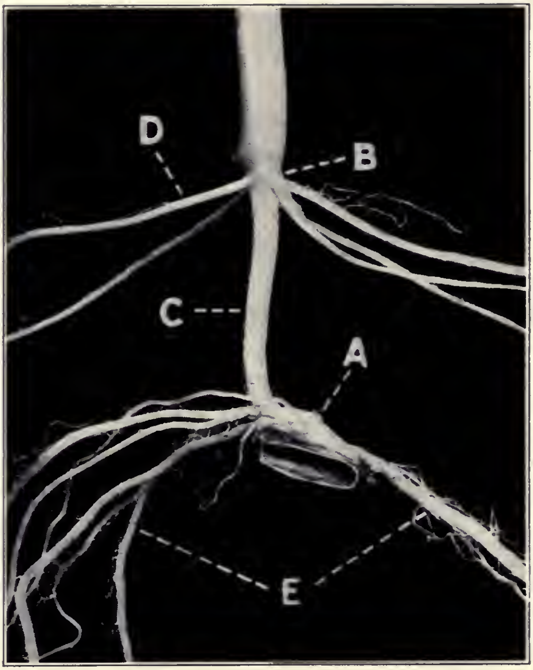


FIG. 20.—PORTION OF A CORN SEEDLING SHOWING (A) FIRST NODE, (B) SECOND NODE, (C) MESOCOTYL, (D) ADVENTITIOUS ROOTS, AND (E) SEMINAL ROOTS

There is some lack of uniformity in the names applied to these parts by scientists. For instance, the seminal roots at *E* are sometimes called primary roots, the adventitious roots at *D,* secondary roots, and the mesocotyl at *C,* first, or subcrown, internode.

to giving the young corn plant a weak start. The actual infection may extend not more than an inch away from the kernel, but it occurs at the most critical time and in the most vital place. So far as is known, the infection does not pass up the sprout farther than the crown where the adventitious roots have their origin (Fig. 20). But as the early growth of the seedling is retarded, fewer and weaker adventitious roots are produced. Weak seedlings usually develop into plants that are handicapped thruout their life period as compared with plants from strong seedlings.[45]*

Several investigators have expressed the opinion that seedling blight and consequent loss in stand is the only important harmful effect that may occur from the use of infected seed, plants that survive being just as thrifty as those grown from clean seed. On the other hand, height measurements of many plants grown from nearly disease-free seed and from seed infected with Diplodia, or

TABLE 2.—EFFECT OF SOME CORN SEEDLING DISEASES ON STAND AND PLANT VIGOR AS DETERMINED BY HEIGHT MEASUREMENTS OF YOUNG PLANTS
(Seasons 1924 to 1927 inclusive, Urbana, Illinois)

Kind of seed used	Replications	Plants measured	Average plant height	Difference in height
	number	*number*	*inches*	*inches*
Nearly disease free	44	14 452	47.4	
Infected with *Diplodia zeae*	44	8 352	43.3	4.1
Nearly disease free	28	7 372	40.3	
Infected with *Gibberella saubinetii*	28	4 515	36.0	4.3
Nearly disease free	40	10 536	38.1	
Susceptible to scutellum rot	40	8 980	36.1	2.0

Gibberella, or seed susceptible to scutellum rot, show that there is a difference in vigor (Table 2). Unfortunately in these tests no measurements were made on seed infected with Fusarium or Basisporium. It should further be borne in mind that in the case of Diplodia and Gibberella infection only about 50 percent of the surviving plants developed from infected seed, the remainder coming from good seed. In order to obtain seed lots of infected seed with very nearly 100 percent viability on the germinator, the percentage of infection cannot be extremely high. The actual percentage of infection ranged from 65 to 90 percent.

The measurements shown in Table 2 were made when the plants were about waist-high, before competition for soil moisture and nutrients became a very important factor in their growth. Two kernels were planted to a hill. As shown in Table 2, the Diplodia and Gibberella infections caused considerable reduction in stand as compared with the stand from the nearly disease-free seed. The differences in stand can be obtained from the columns giving the number of plants measured. If the surviving plants from infected and non-infected seed were equally good, the yield per plant should have been considerably better where the reduced stand occurred, because of diminished competition. In fact, however, the yield per plant in the two groups was nearly equal. This also indicates that the surviving plants were weak.

Losses from seedling diseases depend not only on farm practices, strain of corn, and care used in its selection, but they vary also from year to year depending on climatic conditions during the maturation period.[15*] When wet weather prevails after the ears have attained maturity, so that they remain high in moisture for a considerable time, or when low temperatures kill or injure the plants before the ears are completely mature and while still high in moisture, then infected or disease-susceptible ears are unusually prevalent and the crop from such ears may suffer considerably from various seedling diseases. Concerning this Holbert and Burlison[44*] make the following statement: "Seed from cold-resistant plants has proved superior to that from plants of the same inbreds and recombinations killed prematurely by cold, even when both lots of seed apparently were equal in visible characters and in laboratory germination. This superiority of matured seed from cold-resistant plants expresses itself in increased seedling resistance to disease, in greater cold resistance in the fall, and in greater resistance to lodging and stalk breaking after maturity."

The estimate of average annual loss in the succeeding discussions is based: (1) on the percentages of infection observed in numerous samples obtained from various parts of the state during a period of years; and (2) on actual losses determined in experimental field plots where yields from diseased seed, ranging from 65 to 90 percent infection with each respective disease, were compared with yields of grain obtained from the check plots planted with nearly disease-free seed, as shown in Table 3 on page 61.

DIPLODIA SEEDLING DISEASE

Importance. The amount of Diplodia seed infection varies considerably from season to season and from one location to another in the same year. Still there appears to be a certain amount of seed infected with this disease on almost every farm in Illinois in every season. Infections as high as 30 percent have been noted in what was supposed to be seed corn. The annual loss in yield of corn in the state due to Diplodia seed infection may be estimated at about 2 percent.

FIG. 21.—A HEALTHY SEEDLING (RIGHT) COMPARED WITH OTHER SEEDLINGS GROWN FROM DIPLODIA INFECTED SEED

All four of the infected seeds germinated, but at the time the picture was taken one of the sprouts was already dead, one was dying, and another was so badly decayed at the base that it is doubtful whether it would have grown to maturity. The seedling at the right in all probability would not die as a result of seed infection, but notice the rot at the lower end of the mesocotyl and the poor vigor as compared with that of the healthy seedling.

Symptoms. When Diplodia infected seed is planted, a poor stand and many weak plants are the usual result. The infection is carried within the seed. This may cause the death of the embryo (germ) so that the kernel will not sprout. Much of the infection in carefully selected seed corn, however, is not deep seated enough to injure the embryo. In that case germination begins in the normal way when the grain is planted; but as the embryo begins to grow, the fungus also develops, and very often it overtakes the young shoot (plumule) soon after emergence from the kernel. In this case a blight resulting in the death of the plant is apt to occur. Most of the blighting occurs before the plants come thru the soil. Some plants will die even after they have made as much as six inches growth above the soil. The seminal roots also are attacked by

FIG. 22.—COMPARISON OF PLANTS GROWN FROM DIPLODIA INFECTED SEED AND FROM NEARLY DISEASE-FREE SEED

Plantings were made at the rate of three kernels to a hill. The Diplodia infected seed produced two weak plants (left hill), while the good seed produced three strong ones (right). Photographed 44 days after planting. Compare with Fig. 23. (From Plate V, *Journal of Agricultural Research.*[45*])

Diplodia. In spite of attacks on the roots or mesocotyl, some plants are not killed but struggle along and put forth some adventitious roots at the second node (Fig. 20). After this plants of dent corn are fairly safe from blight, for the fungous invasion is usually stopped at the first node. (In sweet corn the infection sometimes extends farther up the stalk.[121*]) As the mesocotyl ceases to function, the food supply from the kernel and seminal roots is cut off. This causes a great check in the vigor of the seedling (Fig. 21), and thus fewer and weaker adventitious roots are formed. Whether the majority of the infected seedlings will die or survive depends considerably on soil temperature and moisture as well as on the severity of infection and the resistance of the seedling.

FIG. 23.—THE SAME TWO HILLS AS SHOWN IN FIG. 19 PHOTOGRAPHED 120 DAYS AFTER PLANTING

The hill on the left produced less than a pound (.84) of air-dry shelled corn and the hill on the right 2.05 pounds. Corn plants checked by disease in the seedling stage remain weak and yield poorly. (From Plate V, *Journal of Agricultural Research*.[45*])

Weak plants and poor stands may also be caused by other diseases and by insects. There are no above-ground symptoms to indicate whether or not the disease is caused by Diplodia. To make a diagnosis, the seedling must be dug up and the soil carefully removed from the mesocotyl. A dull brown rot of the mesocotyl and a dull brown to bluish discoloration of the kernel is indicative of Diplodia infection. But if the seed coat has reddish markings instead of being a dull brown or slight bluish color, then the disease may be caused by Gibberella, which is the next disease described

FIG. 24.—TYPICAL EFFECT OF DIPLODIA SEED INFECTION ON STAND AND VIGOR OF CORN PLANTS

The row of corn at the left was grown from Diplodia infected seed; that at the right from nearly disease-free seed. Note difference in number and size of plants.

herein. At times mesocotyl rots are caused by still other organisms. The weak plants caused by seedling infection remain weak thruout the season. These differences are illustrated in Figs. 22, 23, and 24. Later in the season there are no symptoms to show that the weakness was caused by Diplodia infection. In addition to causing loss in yield of grain, it has been found that plants grown from Diplodia infected seed are more apt to lodge than those grown from nearly disease-free seed.[68*] This condition is believed not to be caused by a rotting of the roots but to be due rather to the general weakness of the plants resulting from their having been attacked by the disease in the seedling stage. The disease is most severe when the soil is relatively wet during the germinating period.[46*]

Cause. The disease is caused principally by *Diplodia zeae* (Schw.) Lev., a fungus of the class Imperfecti. The mycelium is white when young and becomes gray when old. There is only one kind of spore. It is two-celled, dark in color, averaging 25 by 5.2 microns in size (Fig. 30). These spores are borne in pycnidia which are black in color. The pycnidia are borne on dead cornstalks (Fig. 46), especially near the nodes, on ear shanks, on the cobs of rotted ears, on the rachilla and subtending tissues at the inner ends of the kernels (Fig. 25), sometimes on the kernels themselves, and on the husks (Fig. 26). These dark pycnidia are easily seen with the naked eye. They are somewhat larger in the ear than they are on the other parts. *D. macrospora* Earle and *D. frumenti* E. and E.[23, 103*] have also been reported as causes of corn ear rot in the southeastern states.

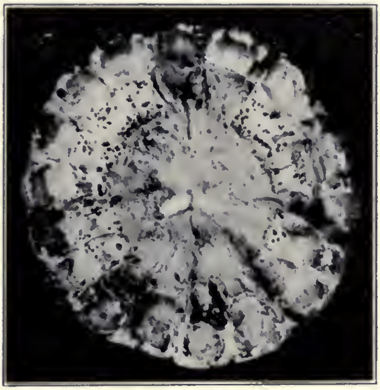


FIG. 25.—CROSS-SECTION OF A DIPLODIA ROTTED EAR, NATURAL SIZE, SHOWING PYCNIDIA

The irregularly rounded black blotches are the pycnidia, or fruiting organs, of the Diplodia fungus. Each pycnidium contains many spores so small that they are invisible to the naked eye.

Seasonal Cycle of Parasite. Pycnidia may be produced in the fall of the year in the various parts of the corn plant mentioned above, but ordinarily most of them do not appear until the following spring and summer, especially on the stalks. During the summer, after a rain, the mature pycnidia open and the spores are liberated. These are carried by the wind to the new corn crop. The aerial parts of normal plants are not subject to infection until the silks appear. From this time until they are too dry in the fall, the ears are subject to Diplodia infection. Such invasion may take place thru the silk, down the husks, thru the shank, or directly on ears not fully protected by the husks.[5, 36, 66*] Soon after silking, the leaf sheaths begin to loosen a little and then infection of leaf sheath and stalk may takeplace.[20*] Considerable moisture, together with dead pollen and Diplodia spores, collects behind the leaf sheaths. The fungus first uses the dead pollen for food.[20*] As the fungus grows, it produces enzymes which break down the delicate tissues of the axillary bud and the fungus enters the stalk there[5*] (Fig. 10). Also it may enter the stalk thru the base of the leaf sheath and thus cause nodal infection. As the corn ear grows to full size, the husks loosen and infection may occur on the ear shank just as it does on the stalk (Fig. 27). The fungus then readily passes thru the shank to the ear.[66*] No pycnidia are formed on the ear or stalk until after these parts of the plant have died.

FIG. 26.—DIPLODIA PYCNIDIA ON INNER HUSKS OF A ROTTED EAR

These pycnidia develop on the husks and shanks, in the ear (Fig. 25), and on the stalks (Fig. 46). Unless destroyed or plowed under, the spores in these pycnidia are carried by air currents to the new crop the following year and cause infection.

Seed infection may cause blight or poor vigor of the resulting plant, but the fungus attack is local, beneath the soil surface, and after the infected parts of the seedling have decayed, the activity of the fungus in that region probably soon comes to an end. It has been shown that *Diplodia zeae* is able to grow on sterilized soil,[20*] but whether it would long be able to maintain itself in competition with the soil flora is questionable. Furthermore it is doubtful whether the fungus would fruit on soil alone. This is important,

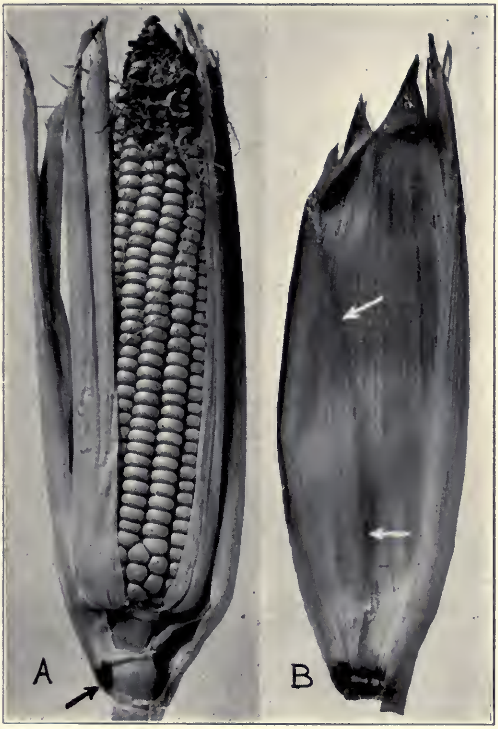


FIG. 27.—DIPLODIA SHANK ROT AT AN EARLY STAGE

The rot started at the base of the husk, as indicated by the arrow in *A*. When this husk was removed (*B*), a brownish rotted streak showed the path by which the fungus had reached the shank. The ear was in the milk stage of development, and when broken off from the shank, a decidedly rotted condition was evident at the break. By harvest time this no doubt would have been a totally rotted ear.

for it appears that the following year's crop is attacked only by infection in the seed or by spores produced on corn refuse and carried by air currents. It is known that infected cornstalks lying on top of the soil may produce spore crops during at least two seasons. Whether the fungus will live that long on buried stalks is not known, but it seems doubtful. If spores are produced on buried material, they cannot get into the air. Such material does not seem to infect vigorously growing corn roots (adventitious system), even when they come in direct contact with them. If all corn refuse could be thoroly eradicated or turned under and kept under the soil surface, the disease would probably be stopped. Unfortunately there are obvious difficulties to such a measure.

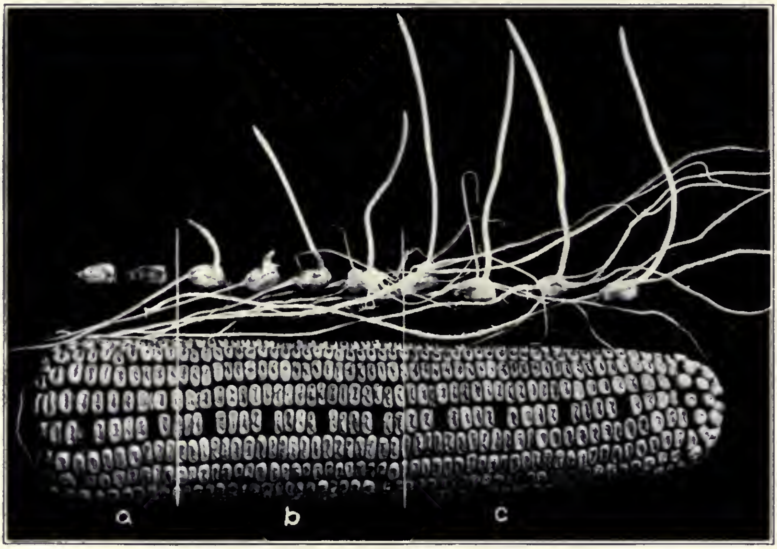


FIG. 28.—DIPLODIA INFECTED EAR SHOWING ZONATION

Infection began at the butt and progressed more than half way up the ear before the ear dried to the point where further growth of the fungus was inhibited. By this time the kernels at the butt were killed. Thus on this ear there are three zones: at *a* the kernels are dead; at *b* they are infected but alive; and at *c* they are healthy. Infection may begin at the butt or at the tip and may extend over the whole ear. Sometimes infection has not progressed far enough to kill any of the kernels.

Control. For the control of the Diplodia disease in general, including ear and stalk rots, field sanitation and crop rotation (pages 18, 19) are recommended. As yet no definite ear or plant types are known to be correlated with resistance to this disease, but it is probable that by thoro elimination of infected ears from the seed lot every year and by selection on the germinator, better resistance may be obtained.

Wide variations exist in the resistance and susceptibility of inbred lines to Diplodia ear rot[41, 47*] (Fig. 54). In many first-generation crosses between inbreds resistant and susceptible to this disease, resistance has been dominant. Crosses between strains that have shown resistance to Diplodia rot have repeatedly had less than 1 percent of the ears damaged by this disease, while in the case of other strains, inbred and crossbred growing under the same conditions, more than 50 percent of the ears were rotted by Diplodia. Open-pollinated varieties also differ widely in their resistance and susceptibility to this disease.

Thus, by employing sanitary measures, by following approved crop rotations, by proper soil management, and by using strains of corn highly resistant to Diplodia ear rot, it is possible nearly to eliminate losses from this disease.

The seedling blight phase can be controlled satisfactorily. Physical selection of seed corn (page 32) eliminates some of the badly infected ears. On a good germinator infected kernels show well-defined symptoms, so that nearly all the infected ears can be eliminated (page 145). Certain seed treatments (page 37) have made possible very good control of the seedling diseases in all cases in which the embryo has not been injured prior to treatment. Seed ears that appear first class frequently carry Diplodia infection. Such ears often exhibit three regions or zones, as shown in Fig. 28. The treatment cannot help zone *a*, which is dead, but it should stop the disease in zone *b* and make the kernels nearly equal to those in zone *c*.

GIBBERELLA SEEDLING DISEASE

Importance. Gibberella seedling disease causes considerable loss in some seasons, while in others it is of little and occasionally of no importance. Whether or not the seed becomes infected depends considerably on weather conditions during the growing period of the corn ear and also on the abundance of inoculum in the atmosphere at that time. Once the seed has become infected, more or less injury to the seedling is apt to occur from the infection unless a seed treatment is used. The average annual loss in yield due to seedling injury by this disease is estimated to be about one-half of 1 percent. Now and then losses may run up to 5 or even 7 percent.

Symptoms. Gibberella seed infection may result in very unsatisfactory stands and much seedling blight in early plantings, especially when such plantings are followed by periods of cold weather. Many infected plants that escape blight are weakened by the disease but continue growth to maturity. These usually lag

FIG. 29.—EFFECT OF GIBBERELLA SEED INFECTION ON STAND AND VIGOR OF CORN

Corn grown from diseased seed makes irregular growth because of differences in degree of resistance to the disease or differences in degree of infection. The irregularity is further emphasized here by the fact that the diseased seed composites contained a small percentage of good seed. Note the comparatively uniform growth in the plants grown from good, nearly disease-free seed.

behind in growth, as shown in Fig. 29. When Gibberella infected seed is planted in rather warm soil, there may be little loss in stand, vigor, or yield.[14*] Such late plantings, however, even with good seed, are not conducive to high yields. The above-ground aspects of this disease are practically identical with those observed in corn grown from Diplodia infected seed. When young diseased plants are dug up carefully, the disease can frequently be distinguished by the characteristic reddish discoloration of the kernel, together with a dark brown rot of the mesocotyl.

Kernel infection on the ear is usually zoned similarly to the

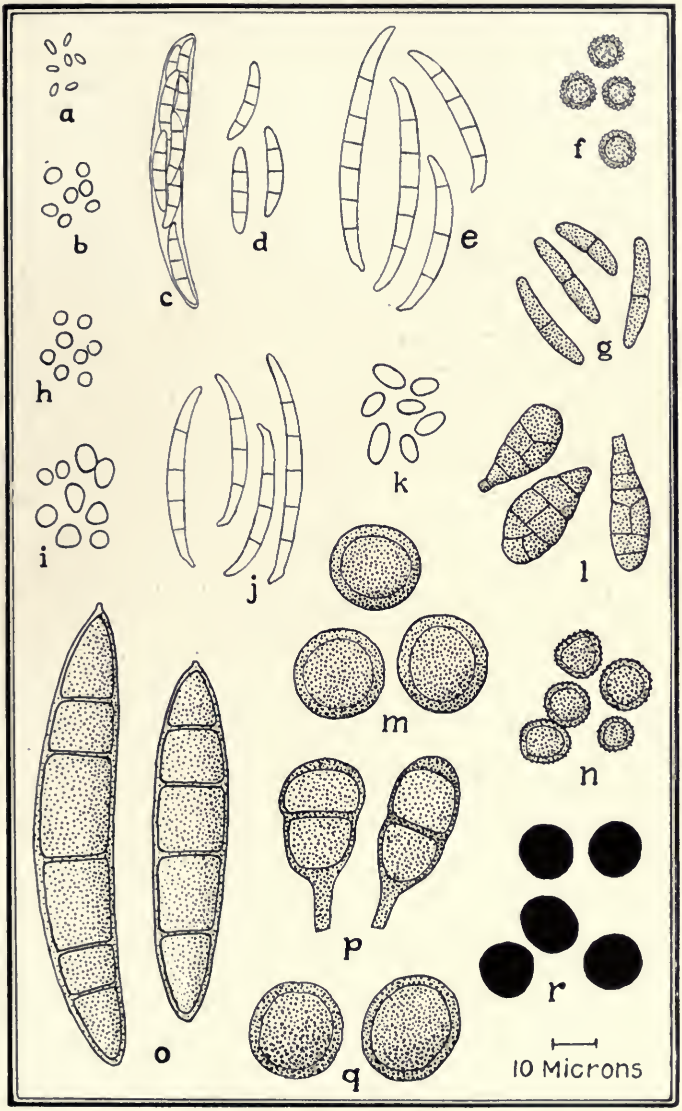


FIG. 30.—SPORES OF SOME OF THE FUNGI THAT CAUSE CORN DISEASES

(*a*) *Cephalosporium acremonium;* (*b*) *Penicillium oxalicum;* (*c*) ascus, (*d*) ascospores, and (*e*) conidiospores of *Gibberella saubinetii;* (*f*) *Ustilago zeae;* (*g*) *Diplodia zeae;* (*h*) *Aspergillus niger* sp.; (*i*) *Rhizopus tritici;* (*j*) macroconidia and (*k*) microconidia of *Fusarium moniliforme;* (*l*) *Alternaria* sp.; (*m*) *Physoderma zeae-maydis;* (*n*) *Sorosporium reilianum;* (*o*) *Helminthosporium turcicum;* (*p*) teliospores and (*q*) urediniospores of *Puccinia sorghi;* (*r*) *Basisporium gallarum.* (Drawn with Cameralucida. All enlarged to same scale.)

situation described for Diplodia. Infection ordinarily begins at the tip end and proceeds toward the butt of the ear.

Cause. This disease is caused by *Gibberella saubinetii* (Mont.) Sacc., a fungus of the class Ascomycetes. The mycelium varies in color from white to yellow and red. Two kinds of spores are produced, conidiospores (conidia) and ascospores. The former are crescent shaped (Fig. 30) 1- to 9-septate tho usually 3- to 5-septate, and ordinarily 30 to 60 by 4.75 to 5.50 microns in size.[117*] The conidiospores when viewed in mass are light pink in color, but when viewed singly under the microscope both kinds of spores appear colorless. When planted on a suitable medium, a conidiospore may germinate and produce a mycelial growth and a new crop of conidiospores within two days.[16*] On corn, however, the development of conidia is relatively slow and sparse. During the germination test of Gibberella infected kernels, a considerable mycelial growth often develops (Plate V) but conidiospores have seldom been observed. They also occur sparsely and sometimes not at all on Gibberella rotted ears (Plate II). On the heads of infected wheat, however, they usually are produced abundantly within three to four days after infection.

The ascospores are produced within perithecia that can easily be seen with the naked eye. The perithecia can often be found in abundance on infected, old cornstalks in the spring of the year (Fig. 47). Sometimes they occur also in considerable numbers on the heads of infected wheat when the grain is mature. Within the ascus are numerous sack-like structures (asci) in each of which 8 ascospores are found. The ascospores are 1- to 3-septate, usually 3-septate, and ordinarily 20 to 30 by 3.75 to 4.25 microns in size (Fig. 30).

Seasonal Cycle of Parasite. The fungus lives over winter in infected refuse of small grains and in infected cornstalks. Whether Gibberella rotted ears left in the field are of importance in carrying the disease over has not been determined but it is reasonable to suppose that they are. Ascospores produced on old cornstalks left on top of the ground are probably the chief source of infection for the succeeding crop. These ascospores are liberated during the growing season. If damp weather prevails for a few days immediately after the small grains have headed out, there may be an epidemic of scab of wheat and barley. Rye and oats also may become infected. After the silks are out, ear and stalk infection takes place in corn under suitable weather conditions. The fungus may persist for some time in infected cornstalks, or in straw and other grain refuse when it is covered with soil, but in that case the spores cannot get into the air to reinfect the new crop. Such infected refuse in the soil, when abundant, may be a factor in causing rot of corn roots or mesocotyl that come in contact with it, much more so than Diplodia infected refuse. To what extent the fungus is able to live in the soil apart from infected refuse is not known, but it appears to be able to do so to some extent.

The fungus lives over winter in infected seed and causes the seedling disease. The attack is beneath the soil surface and the fungus does not spread very far from the kernel. When the diseased seed is held over for a year before planting, the fungus dies out and the infection is gone. All other seed infections here described that cause seedling injury are longer lived.

In addition to attacking the cereals, this fungus has also been found on sweet potatoes[117*] and possibly on some other crops.

Control. As in the case of Diplodia disease, if sanitation (page 18) were practiced thoroly and on an extensive scale, the disease would probably no longer be of serious consequence. This would involve not only the turning under, putting in silo, or burning of all corn refuse but also of the straw of scab-infected small grains. For the control of Gibberella corn ear infection alone, such a measure would not be practical, but as scab of small grains is controlled thereby and as a number of other corn diseases also are controlled by removing or plowing under corn refuse, sanitation measures no doubt are highly worth while. Altho this measure is not so effective if confined to a single farm, even in that case it is worth while and should be encouraged. A suitable system of crop rotation is also of considerable help, especially when sanitary measures cannot be carried out satisfactorily. For best disease control, corn should not be followed by corn, wheat, or barley in the rotation, for these are the crops that are most susceptible to Gibberella infection.

Physical selection of seed corn (page 32) eliminates some of the very badly infected ears. The germination test (page 147) further helps in culling out infected ears. Seed treatment controls the disease on kernels not too badly infected. It has been observed that under some conditions much of the slight Gibberella seed infection will fail to become evident in the ordinary germination test made at a temperature of 75° F. or over. Yet when planted in cool soil, as usually occurs at the proper corn planting time, much injury may result. In such cases seed treatments are especially valuable as a supplement to the germination test.

It has been found that various selections and strains of corn differ widely in their resistance and susceptibility to Gibberella-seedling blight.[46, 67*] Corn grown from seed selected according to the recommendations set forth in this bulletin has been found to be highly resistant to injury from the seedling phase of this disease.[46*] And, as in the case of Diplodia ear rot, strains of corn inbred, crossbred, and open-pollinated—vary greatly in their resistance and susceptibility to Gibberella ear rot. Some strains have been found whose ears over a period of years have been damaged only very slightly by this disease.

FUSARIUM SEEDLING DISEASE

Importance. Practically every seed lot in the state every year is infected with *Fusarium moniliforme,* and usually the percentage of infection is high, frequently running over 50 percent. Fortunately this fungus is not usually a vigorous pathogen; its importance lies in the fact that the percentage of infection runs so high.

In experimental tests in Illinois reductions have usually been observed in yields of corn grown from seed naturally infected with *Fusarium moniliforme* (Table 3). On the other hand, inoculating nearly disease-free seed by moistening the seed coat with a spore suspension of the organism before planting apparently did not cause infection, for it caused no decrease in yield.[46*] This is no surprise, for even with such a vigorous pathogen as *Diplodia zeae,* under field conditions suitable for the vigorous growth of corn infection usually is not obtained by inoculating the seed in the manner just mentioned. Investigators in several other states have expressed doubt as to whether seed infection with *Fusarium moniliforme* is a factor in reducing yield.[25, 77, 98*] One of these reports[98*] is based on evidence that seems to be inconclusive. Some of the infected seed was treated so as to kill the infection, while some of the seed was left untreated. The treated seed yielded less than the untreated, but the treatment was a drastic one, and therefore any

TABLE 3.—COMPARATIVE YIELDS OF YELLOW DENT CORN GROWN FROM GOOD SEED, FROM VARIOUS KINDS OF INFECTED SEED, AND FROM SEED SUSCEPTIBLE TO SCUTELLUM ROT

(Grown in various places in Illinois, 1917-1929 inclusive)

Kind of seed used	Years covered by experiments	Number of experiments	Acre yield		Reduction in yield following use of diseased seed	
			Good corn	Diseased corn		
			bu.	*bu.*	*bu.*	*perct.*
Good	10	93	63.8	....		
Diplodia infected	10	93	....	41.5	22.3	35.0
Good	6	37	59.8	....		
Gibberella infected	6	37	....	45.0	14.8	24.7
Good	4	20	60.5	....		
Basisporium infected	4	20	....	51.8	8.7	14.4
Good	9	55	63.9	....		
Fusarium infected	9	55	....	58.0	5.9	9.2
Good	8	31	58.1	....		
Cephalosporium infected	8	31	....	54.4	3.7	6.4
Good	10	63	70.9	....		
Scutellum rot susc.[1]	10	63	....	58.8	12.1	17.1
Good	5	16	51.1	....		
Scutellum rot susc.[2]	5	16	....	49.0	2.1	4.1

[1]Seed composites selected from corn that had received no previous selection for resistance to scutellum rot.

[2]Altho the ears used in these seed composites showed susceptibility to scutellum rot on the germinator, they were taken from seed lots that had been bred for resistance to this disease for a number of years.

benefit that might have been derived from killing the fungus very likely was more than offset by the injury caused by the treatment. It is possible, of course, that under some conditions little or no harm occurs from this infection. Differences in pathogeneity of different strains of the fungus no doubt exist. Considerable variation in amount of loss has been found in different tests in Illinois, but the reasons therefor have not yet been fully explained. Soil conditions, the genetic complex of the corn, and the other environmental conditions no doubt are all factors in this problem.

The statement made by Melchers and Johnston,[78*] "The freedom of seed on the germinator from *F. moniliforme* does not seem as important in securing a satisfactory stand and yield of corn in Kansas as seedling vigor," probably also holds for Illinois. Seedling vigor is always an important consideration. Seed poor in vigor is undesirable even tho it appears to be free from infection.

From data obtained in various parts of the state during the last eight years, it is estimated that the annual loss in yield due to seed infection with *Fusarium moniliforme* is about 1 percent.

Symptoms. There are no outstanding field symptoms associated with plants grown from seed infected with *Fusarium moniliforme.* When stands from infected seed are compared with stands from nearly disease-free seed, small reductions in stand and vigor usually are found. Actual counts of the stand must be made, for ordinary observation does not very readily reveal it. Fusarium seed infection usually also causes a reduction in yield of grain, but here again actual weights must be taken, for no one can estimate a difference of something like 5 percent in yield without some reliable way of actually measuring it. For symptoms during the germination test, see page 141.

Cause. As perithecia of this fungus have not yet been observed developing under natural conditions, the fungus is still ordinarily known as *Fusarium moniliforme* Sheldon. This is a species of the class Imperfecti. It produces two kinds of conidiospores, microconidia and macroconidia (Fig. 30). The former are oval in shape, 2 to 3.5 by 5 to 10 microns in size.[116*] They are produced in chains (Fig. 67). In mass the conidiospores are a pale pink in color, but when viewed singly under the microscope they appear colorless. When a spore is planted under suitable conditions, a new crop of microconidia will develop in a few days. Macroconidia usually are slower in developing; these are 3- to 5-septate, and 2.9 to 3.2 by 32 to 56 microns in size. They are borne singly, not in chains.

Ascospores have also been found as a spore stage of this fungus. They were observed by Wineland[116*] in cultures of the fungus isolated by the senior writer from yellow dent corn grown near Bloomington, Illinois. This puts the fungus in the Ascomycete class and therefore the name *Gibberella moniliformis* (Sheldon) Wineland has been given it. The perithecia resemble those of *Gibberella saubinetii* and it has been suggested[116*] that they may have been seen in nature, but that they were mistaken for the better known perithecia of the latter fungus. The ascospores, however, are distinctive in appearance (Fig. 30). They are 1- to 3-septate, the 1-septate predominating, and are 3.9 to 4.8 by 15 to 19 microns in size. There is no reason to doubt that these strains, which produced the ascigerous stage in the laboratory, would also produce the same under natural conditions. On the other hand, there appear to be many strains or varieties of this fungus,[74*] and from what is known so far, it seems likely that many, if not most, of these strains do not produce the ascigerous stage. It therefore seems preferable for the present to retain the Fusarium name.

Seasonal Cycle of Parasite. Fusarium moniliforme is able, apparently, to winter on crop refuse of various kinds. It probably does not live in the soil very long after all refuse has decayed completely. Spores developing on infected refuse exposed to the atmosphere are carried by the winds to the new corn crop. The ears become susceptible to infection immediately after silking. Ordinarily most of the infected ears do not show the infection externally but the infection can be seen on the kernels during the germination test (Plate III). On infected ears, kernels with an injured seed coat, whether the injury is due to physiologic cracking (Fig. 59), worm injury, bird pecking, or other cause, usually develop this rot, especially in the starchy types. Some starchy ears also develop the rot without previous seed-coat injury. The fungus is also reported as causing a blight of pine seedlings, root rot of older pines, a rot of potato tubers, a root rot of cotton, and it has been found on dead parts of banana plants. There may be other susceptible crops.

Control. Good sanitation and crop rotation (pages 18, 19) would be expected to help in reducing ear infection and ear rot. Ear selection for a horny, utility type, early enough to mature well in an average season, has also been of considerable help in reducing ear rot. Strains of corn have been developed that are highly resistant to ear rots caused by *F. moniliforme.* For the control of the seedling disease caused by this fungus, careful attention to soil fertility, especially with respect to an adequate phosphorus supply,[46*] is of importance. The germination test (page 141) will help in removing badly infected seed ears. Seed treatments (page 37) have proved partially effective in controlling this seedling disease.

BASISPORIUM SEEDLING DISEASE

Importance. The disease called "cob rot" has been known for many years, but that the fungus causing cob rot also frequently occurs in an inconspicuous way on what might be considered as seed corn has not been known very long.[22*] The prevalence of seed infection varies from year to year, heavy infection occurring when the fall is damp, especially when the dampness follows damage that resulted from the occurrence of frost while the ears were high in moisture. From the limited data available, an estimate of the average annual loss due to seed infection is difficult to make. A conservative figure would seem to be about 1 percent (Table 3).

Symptoms. The field symptoms of Basisporium resemble those observed with Gibberella and Diplodia infections. Some infected seed is dead. Some will germinate but the plants die in the seedling

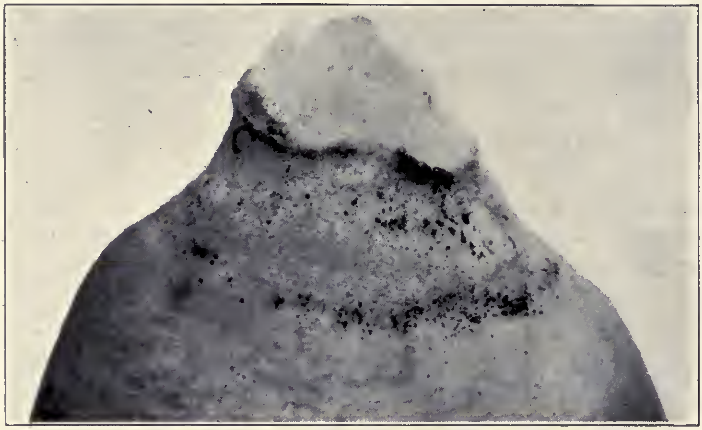


FIG. 31.—BASISPORIUM SPORES AT THE TIP END OF A CORN KERNEL

This corn kernel is enlarged 12 times. With the naked eye the presence of these spores could hardly be discerned. Sometimes the spores are so numerous that they are easily seen (Fig. 16), sometimes they can be detected only with hand lens or microscope, and often they do not occur at all even when the kernels carry Basisporium infection.

stage. Both conditions result in a poor stand. Still other infected seedlings survive but are weakened by the infection. The disease differs from that caused by Gibberella or Diplodia, however, in that the germ of good-appearing seed that is infected with Diplodia seldom is injured prior to planting, the disease doing its damage when the kernels germinate. Basisporium, on the other hand, attacks the germs especially, so that even before planting, the germs of good-appearing but infected seed sometimes have been injured and will produce weak plants. This is one of the reasons why seed treatments are not always so effective with Basisporium infection as they are with Gibberella and Diplodia seed infections.

The symptoms that most clearly indicate infection with Basisporium occur on the dry ear and kernel. Infection of the ear may occur thru the shank or tip. When it has occurred thru the shank, Basisporium spores often are visible around the shank attachment (Fig. 12). Badly infected kernels show the spores at the tip end (Fig. 16), but when infection is light, a good hand lens is necessary to see them (Fig. 31). Often the infected kernels show only a yellowish discoloration on the lower end of the germ portion, no spores

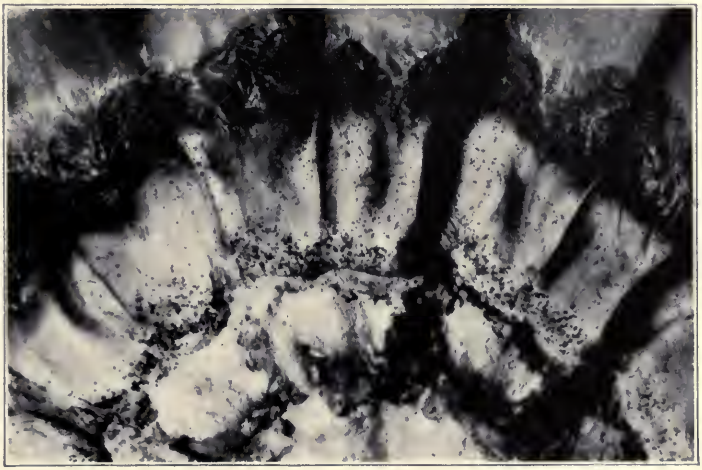


FIG. 32.—BASISPORIUM SPORES ON THE RACHILLAS AS SEEN WHEN AN EAR IS BROKEN CROSSWISE

When Basisporium ear rot becomes extensive in an ear, the cob breaks very easily and spores, as shown here, are numerous. Such ears usually are light and chaffy. When the infection occurs late, however, the cobs are strong and no spores are visible. (Enlarged 5 times.)

having developed at all, and sometimes what appear to be perfectly good kernels carry the infection. Usually Basisporium infected ears are zoned. At the butt end of the ear there may be a zone in which masses of spores on the kernels are clearly evident to the naked eye (not all infected ears show spores, however), next there may be a zone in which the spores are few in number so that they can be detected only with a magnifying glass, and next to that there may be a zone in which the kernels are infected but no spores have developed. (See Fig. 28 for zoning caused by Diplodia).

Cause. This seedling disease is caused by *Basisporium gallarum* Moll., a fungus of the class Imperfecti. The spores are black in color, averaging 11 by 14 microns in size (Fig. 30). Altho the individual spores are too small to be seen with the naked eye, they often occur in groups that can easily be seen (Fig. 16) and they sometimes occur in a solid black mass. They can be found on the protected portions of the husks, on the surface of the shanks beneath the husks, on the inner surface of the leaf sheaths, around the shank attachment of the ear, on the surface of the cob (especially on the surface of the rachilla, Fig. 32), and on the kernels.

Seasonal Cycle of Parasite. The fungus overwinters in good condition on old infected cornstalks, shanks, and ears. After the ears begin to develop and the leaf sheaths and husks begin to loosen, infection of the new crop by wind-blown spores may take place. Damp weather conditions seem to be necessary in order for infection to occur.[22*] Under suitable conditions heavy infections of stalks, shanks, and ears may be found, while under some other seasonal conditions the disease is comparatively rare. It seems probable that Basisporium will not attack vigorously growing tissues but is able to become established only after the tissues have been reduced in vitality by disease, mechanical injury, low temperatures, or other cause.

When a corn strain is unadapted to the soil conditions in which it is grown, or when the supply of soil nutrients is inadequate for a particular strain of corn, so that the plant does not mature normally in the fall, then high percentages of Basisporium infection are likely to be found. The same situation obtains when the corn is so constituted genetically that it does not attain full maturity before cold fall temperatures set in. There is considerable difference in resistance between different strains as well as between individual ears within an open-pollinated strain. Some strains are very susceptible to Basisporium infection, even to the extent of more than 50 percent of the ears being badly damaged by this disease following maturity and prior to harvesting, while other strains of corn, under comparable conditions, have been damaged only slightly.

Resistance, no doubt, also wanes with the approach of maturity. The ears of strains maturing very early are likely to become infected with this ear rot fungus during the warm wet weather that so frequently obtains during periods in September and October.

Basisporium gallarum has also been reported as causing a fruit rot of tomato.

Control. An important consideration in the control of Basisporium ear rot is the selection of a strain of corn capable of maintaining a physiologically balanced growth in the soil and under the prevailing climatic conditions of the place where it is grown. Corn strains that mature unusually early in the fall—or, in other words, strains that dry up and die before cold weather sets in—should be avoided when the crop is to be cribbed or stored. Strains utilizing the full growing season and that at the same time are capable of effecting complete maturity under the environment in which they are grown should be chosen. Ears of strains maturing too late are subject to infection following injury by low temperatures in October or November. Corn strains that appear to be particularly susceptible to this disease should be replaced by better strains.

As for seedling infection, close attention to selection of the seed ears (page 32), with special attention to examination for the presence of the Basisporium spores (Figs. 12 and 16), is the most important consideration. A good seed treatment also has been found to be of value and should be used, for many of the lightly infected ears cannot be eliminated by the above methods. The germination test frequently is of but little help, for ordinarily no symptoms develop on the germinator that cannot be observed on the dry grain. While the moisture on the germinator does appear to make the spores more clearly visible at times, on the other hand, other fungus growths may develop which completely hide them. (For symptoms on the germinator see page 149.)

SCUTELLUM ROT DISEASE

Nature of the Disease. Unlike most of the other parasitic diseases discussed in this bulletin, scutellum rot is not caused by any one or more specific organisms; many different organisms are involved most of which might be classed as "weak" parasites that usually live as saprophytes. Furthermore the scutellum is by no means the only part involved. The name "scutellum rot" has been used because disease susceptibility of this type can usually be recognized by the development of scutellum rot on the germinator (page 136). For the present purpose all the effects caused by fungous or bacterial invasion of the endosperm or scutellum, and infections starting at the bases of the roots not due to other specific diseases are grouped here. Resistance to this kind of infection no doubt is of a chemical nature.[65]* Furthermore this resistance, when it occurs, apparently is not confined to the seedling. Plants grown from seed very susceptible to scutellum rot often have been found to be more susceptible to stalk rots and ear rots than those grown from seed resistant to scutellum rot.[46]* Furthermore susceptibility to scutellum rot is correlated to a considerable degree with immaturity.[65]* Corn from susceptible seed very often is of a plant type that will not attain complete maturity unless the season and other conditions are unusually favorable. The plants may become dry at the usual time and the ears present the superficial appearance of being mature, but being physiologically immature the full possibilities of yield of grain is not attained. As the moisture content of such ears in the fall usually is greater than in fully matured ears, the hazard from ear rots in the field and in storage is considerably aggravated.

Importance. In estimating the importance of the scutellum rot disease, the various features mentioned above must be considered. It is evident that there are seasonal variations in the importance of the disease and that there are wide variations in losses from farm to farm varying with strain of corn used, care taken in seed selection, and attention given to soil management. Considerable knowledge concerning the three factors mentioned has been attained and put into practice during the last ten years so that the losses from scutellum rot now are not so great as they were in the previous decade. Nevertheless the annual losses now are estimated to be fully 5 percent (Table 3).

Symptoms. Plants grown from seed susceptible to scutellum rot usually are less vigorous than those from resistant seed. They have shorter or more-slender shoots, fewer or less-sturdy roots, and fewer laterals branching off from the first or main root. On account of impaired vigor the chances that the plant will be able to push its way up thru the soil are reduced and a decrease in stand therefore usually occurs (Table 2). When infected plants are taken from the ground and the kernels are cleaned from soil and bisected, a rot similar to that found on the germinator (Fig. 65) often can be seen. In rich well-pulverized soil there is less damage than in poor soil, for in the rich soil the young roots are able to supply nourishment sooner and the plants come thru the soil more easily. Other things being equal, the vigor of the older plants and the yield of grain are in proportion to the vigor of the young plants.[45*] (For symptoms on the germinator see page 136.)

In experiments previously reported,[67*] it was demonstrated that susceptible seed (susceptible to scutellum rot on the germinator) in comparison with resistant seed produced a lower yield of grain on infested soil than it did on clean soil. It appeared that the difference was largely due to differences in the severity of root rot. It was also shown in the same publication that after the stalks had lain in the field until the following summer, there were considerably more perithecia of *Gibberella saubinetii* on the stalks grown from susceptible seed than there were on stalks grown from good seed. Thus seed susceptible to scutellum rot also appeared to be more susceptible to root and stalk rot. In an article by Reddy and Holbert[89*] (Table 16 of reference) data are given showing that inoculations with *Cephalosporium acremonium* or *Aplonobacter stewarti* made into the stems of plants grown from susceptible seed (susceptible to scutellum rot) caused greater losses to yield of grain than when inoculations were made into stems of plants grown from good seed. Thus susceptibility to scutellum rot was correlated with susceptibility to stalk infection with these organisms. It was shown also, in the same table, that the inoculation of seed with *Gibberella saubinetii* at planting time was more detrimental to seed susceptible to scutellum rot than to good seed. Further data involving these two types of seed also show marked differences in resistance to infections from seed inoculations with *G. saubinetii* (see pp. 423-425 of Holbert *et al.*[46*])

TABLE 4.—YIELDS AND PROPORTIONS OF UNMARKETABLE EARS FROM GOOD YELLOW DENT CORN AND FROM YELLOW DENT CORN SUSCEPTIBLE TO SCUTELLUM ROT, AS AFFECTED BY TIME OF PLANTING
(University South Farm, Urbana, five-year average, 1921-1925)

Date of planting	Character of seed	Acre-yield			
		Total	Sound	Unmarketable	
		bu.	*bu.*	*bu.*	*perct.*
May 2-4	Good	66.0	57.0	9.0	13.6
	Susceptible	53.1	42.7	10.4	19.6
May 10-14	Good	65.1	55.2	9.9	15.2
	Susceptible	54.3	43.7	10.6	19.5
May 20-22	Good	62.2	53.0	9.2	14.8
	Susceptible	50.5	39.1	11.4	22.6
May 30-31	Good	58.2	47.6	10.6	18.2
	Susceptible	46.0	33.1	12.9	28.0

In another publication[45*] it was shown that there was considerably more ear rot in corn grown from susceptible seed than in corn grown from good seed. In other tests where the ear rots were not considered specifically but the percentages of sound and unmarketable corn were determined, it was found (Table 4) that the percentages of unmarketable corn averaged higher when susceptible seed was used than when good seed was used. Furthermore this difference was greater in the late plantings than in the earlier planting. (See also Fig. 17 of Holbert *et al.*[45*])

Thus it seems evident that scutellum rot reduces the stand and vigor of plants; and that seed susceptible to scutellum rot produces plants susceptible to Giberella seedling disease, to stalk infection by *G. saubinetti*, *C. acremonium*, and *A. stewarti*, and to several kinds of ear rot. Resistant seed has, on the whole, shown greater resistance to these other diseases also.

Cause. Many fungi are able to cause scutellum rot. On the germinator, species of Rhizopus are usually the cause, altho Penicillium and Aspergillus species also cause certain types of scutellum rot at times. Under field conditions the above-mentioned fungi also are of importance but they are not the predominating ones. From corn grown in soil, species of Fusarium, Mucor, Trichoderma, and Pythium have been isolated from infected scutellum in addition to those mentioned above. Fusarium species were isolated most frequently. Penicillium species were second in frequency and Mucor species third.

It has frequently been observed that losses in yield due to the use of seed susceptible to scutellum rot are greater where corn follows a previous corn crop than where no preceding corn crop had been grown for some years.[46*] Possibly this indicates that the corn becomes infected with more virulent organisms in one case than in the other. The identities of the organisms causing scutellum rot or seedling infection under different cropping systems have not been studied.

Seasonal Cycle of Parasites. Probably all the parasites occurring in connection with scutellum rot live usually as saprophytes; that is, they can grow and multiply by feeding on dead organic matter and do not need live plants for food. Their spores occur abundantly in nature—in the air, and in the soil—some predominating under certain conditions, others under other conditions. Most of them are

FIG. 33.—CORN PLANTS GROWN FROM NEARLY DISEASE-FREE SEED AND FROM SEED SUSCEPTIBLE TO SCUTELLUM ROT, PLANTED AT DIFFERENT DATES

Good seed yielded best when planted early (May 1 in central Illinois), but seed susceptible to scutellum rot yielded best when planted at an intermediate date (May 10). In any event, the yield from disease-susceptible seed was lower than that from good seed. (See also Table 4.)

not carried as internal infection of the seed, but cause infection from the outside when the kernels germinate. Penicillium and Aspergillus species are exceptions, as they are sometimes carried also within the seed.

Control. Careful attention to ear selection (page 32) eliminates a large proportion of the susceptible ears. Immature kernels or those with the endosperm showing a soft, floury condition are usually especially susceptible. Not all well-matured ears, however, are highly resistant. Susceptibility varies with different ears that otherwise appear alike, and varies also to some extent with individual kernels on a single ear. For the best results, therefore, selection by means of a germination test (page 136) should be made following physical selection. Eliminating ears susceptible to scutellum rot is important, not only because it tends to eliminate the seedling disease caused by scutellum rot, but also because corn grown from ears susceptible to scutellum rot apparently is very susceptible to root, stalk, and ear rot also, as has been pointed out.

A good system of crop rotation (page 19) is of some benefit when susceptible seed is planted. Altho nearly disease-free seed yields best when planted relatively early (about May 1 for Reid Yellow Dent at Urbana), when seed susceptible to scutellum rot has to be used, best results are obtained if it is planted some ten days later (May 10). This coincides with the average corn planting time in this locality under present practices (Fig. 33).

PENICILLIUM SEEDLING DISEASE

Importance. As the Penicillium seedling disease has been described only recently,[55, 56*] no estimate of its importance under ordinary conditions can be made. The fact that *Penicillium oxalicum* has frequently been isolated from corn ears and that pure-culture seed inoculations have caused striking reductions in stand and vigor as compared with check plots grown from similar but uninoculated seed, all grown under favorable field conditions, indicates that the disease may be of considerable importance.

Symptoms. Penicillium has been mentioned in the discussion of scutellum rot. The species described here, however, often invades the base of the plumule and primary root directly, rather than becoming established first in the scutellum. From there the infection proceeds up the mesocotyl, and considerable loss in stand may re-

FIG. 34.—CORN SEEDLINGS GROWN FROM GOOD SEED (A), AND FROM PENICILLIUM INFECTED SEED (B)

Penicillium oxalicum causes a reduction in vigor, and in severe cases a blight of the seedlings. Notice the rot at the base of the mesocotyls.

sult from blighting of the seedlings. Quoting Johann:[55*] "The first symptom of invasion by the Penicillium was the light yellow-green color of the basal half of the upper leaves. This shaded into a normal green at the tip of the leaf. As the disease progressed, the tips and margins of the leaves became dry. Eventually all the leaves became dry without a striking change in color." Many infected seedlings live but are stunted. This condition as well as blighting (Fig. 34) is responsible for losses to the crop, for plants weakened by seedling diseases usually do not produce a normal yield of grain.

Cause. This disease is caused by *Penicillium oxalicum* Curie and Thom (Fig. 1). It belongs to the class Imperfecti. The conidiospores are somewhat ovoid (Fig. 30), measuring 2 by 3 to 3.5 by 5 microns in size. The fungus when fruiting appears bluish green (Plate V). When the spores are viewed singly under the microscope, they appear almost colorless.

Seasonal Cycle of Parasite. The fungus has frequently been found on moldy corn and cornmeal and also seems to be common in soil.[11*] Its occurrence, therefore, appears to be rather general. Penicillium infection often becomes established in the corky tissues of the cap at the tip end of the kernel before the ear has become dry. Spores coming in contact with the surface of the dry kernel very likely also cause the disease. When such infected seed is planted, the fungus causes a rot of the embryo and the rot may also extend up the mesocotyl. It has been found[55*] that the cells are killed in advance of the fungus invasion, and it has been suggested that this killing of the cells is due to the diffusion of oxalic acid which is produced by the fungus.

Control. Careful selection of ears for physical appearance will probably eliminate some of the more susceptible ears. Infected ears can be detected on the germinator. The value of seed treatment has not been determined. The pure-line method of breeding offers promise that high resistance to the disease may be attained.

ASPERGILLUS SEEDLING DISEASE

Altho black, yellow, green, and brown species of Aspergillus often are factors in the development of scutellum rot, some symptoms that are distinctly different from scutellum rot have been observed by the senior author on corn seedlings grown from seed that was inoculated with certain species of Aspergillus. Inoculations were made with four different cultures, all being isolations from corn kernels and belonging to the following group species: one *A. niger,* one *A. tamarii,* and two *A. flavus.* These inoculations were made by moistening the seeds with a spore suspension of the fungus just before planting. Plantings were made in earthenware pots in the greenhouse.

Each of the last three cultures mentioned produced chlorosis on the corn leaves (Fig. 35). This occurred under cool (60° F.) and warm (80° F.) temperature conditions and in several different types of soil. One of the *A. flavus* strains was less active in this respect than the other *A. flavus* and the *A. tamarii.* Most of the inoculated seedlings appeared perfectly white when they emerged. By the time the second leaf appeared, the tip end of the first leaf in many cases took on some green color and the plants could then be classed as

FIG. 35.—TWO HILLS OF CORN, THE ONE AT THE RIGHT INJURED BY *Aspergillus flavus*

Infection was produced by inoculating the kernels with a spore suspension of this fungus at planting time. This caused the greater part of the leaf surface to remain white during the early seedling stage and also caused poor vigor and blighting of some plants.

virescent.[13*] As new leaves appeared they were at first white, then virescent, and finally green when the adventitious root system became active and the plant assumed normal characteristics. Some seedlings, however, failed to produce sufficient chlorophyl to remain alive and consequently died in about the third leaf stage. The uninoculated checks were all thrifty and normal green in color.

These results were very striking when the corn was grown in the greenhouse during the winter months. The experiment was repeated during several different seasons with similar results. But when the inoculated corn was planted in the field in May, very little evidence of virescence was noted. It seems likely that the difference in the quality of the light under these two conditions accounts for the difference in results.

Similar inoculations made with a species of the *A. niger* group produced a more pronounced rot of the embryo region and mesocotyl, so that there was a decided reduction in vigor but the plants were not virescent (Fig. 36). The mesocotyl rot was not so severe as occurs in the case of Diplodia or Gibberella infection. *A. niger* and *A. flavus* both invade the inner tissues of the mesocotyls (Fig. 37).

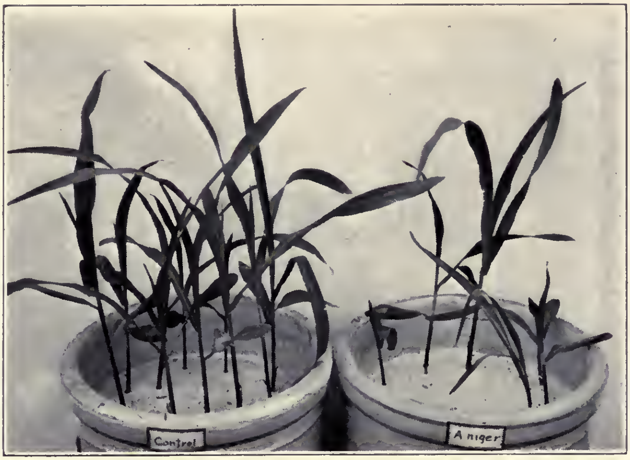


FIG. 36.—EFFECT OF SEED INOCULATION WITH *Aspergillus niger* ON GROWTH OF CORN SEEDLINGS

Ten kernels of yellow dent corn susceptible to scutellum rot were planted in each of these pots, which were filled with virgin brown silt loam soil. The seed in the pot at the right was inoculated by moistening the kernels with a spore suspension of the fungus just before they were planted. Note reduction in stand and vigor. White sand was placed over the soil before photographing in order to show the plants better.

This occurs readily in the absence of any visible external evidence of rot of these organs, the fungus gaining entrance at the base of the primary roots or thru the scutellum. Under field conditions the inoculations with *A. niger* caused a reduction of several bushels per acre in yield. Taubenhaus[106*] in Texas also has reported on deleterious effects on corn seedlings due to Aspergillus species.

From these investigations it appears likely that some of the Aspergilli may be factors in the reduction of seedling vigor and the production of blight aside from the role they play in the development of scutellum rot.

FIG. 37.—MESOCOTYLS INVADED BY *Aspergillus flavus* (A) AND *Aspergillus niger* (B)

When the plants were of the size shown in Figs. 35 and 36, they were washed clean from soil, the mesocotyls were removed, surface-sterilized, washed in sterile water, and a portion removed from each end with scissors that had been flamed. Each fragment thus represents a medial section of a mesocotyl with all living organisms excluded except such as might be in the internal tissues of these fragments. Healthy internal tissues are sterile. In this case, however, these fungi had invaded the mesocotyls, and as a result of the technic here used the fungi have grown out of the ends of the fragments and have established colonies on the culture medium.

SCLEROSPORA SEEDLING DISEASE

Unlike the preceding diseases, Sclerospora seedling disease does not seem to be caused by seed infection but rather by infection from the soil. Only the young plants are susceptible.[80*] The disease is caused by *Sclerospora graminicola* (Sacc.) Schroet. The same fungus causes a mildew on green foxtail, which is a common and troublesome weed in most cornfields. This disease has not yet been observed on corn in Illinois, but as it has been found in Iowa[80*] and Wisconsin[114*] it probably also occurs here.

Infected seedlings are stunted; some die when only several inches high while others survive the attack. The diseased seedlings may show a mildew effect on the leaves, but this does not always occur. Ordinarily, Sclerospora infection on corn probably is rare.

PYTHIUM SEEDLING DISEASE

See Pythium root rot, page 91.

GENERAL DISEASES OF THE AERIAL PARTS

BLACK BUNDLE DISEASE

Importance. The black bundle disease causes considerable loss of corn. Reddy and Holbert[89*] in surveys of commercial cornfields near Bloomington, Illinois, during the years 1919, 1920, and 1921 found 6.6 percent of the plants showing typical external symptoms of this disease. Of these diseased plants 50.5 percent were barren, 19.6 percent bore only nubbins, and 29.9 percent bore ears. L. R. Tehon and G. H. Stout, in plant disease surveys of Illinois, have obtained extensive data on the prevalence of the black bundle disease during the seasons 1924 to 1928.[a] During this period they found that an average of 3.9 percent of the plants showed definite symptoms of the disease. Most of these plants were barren or produced only small nubbins. The data also show a slight preponderance of the disease in the southern part of the state as compared with the northern region. In some fields infection of 70 percent of the plants was observed, while in some others the amount was negligible. Differences as striking as this have been observed on adjacent farms. From these surveys it would appear that the average annual loss in yield from the disease in Illinois is about 3 percent.

Symptoms. The black bundle disease cannot be easily recognized until the corn is in the dough stage. In ordinary strains of corn in which the stalks normally are green, one of the outstanding symptoms of the disease is the occurrence of a reddish-purple color of the stalks and leaves. Purpling begins with the uppermost leaves and progresses downward. Usually the midrib shows coloring sooner than the rest of the blade. Very often these stalks are barren or bear only nubbins. Often a number of these nubbins occur together at the same node (multiple ears), as shown in Fig. 38, and sometimes attempts at ear formation occur at an unusual number of nodes (prolific ears) on plants that normally would produce only one or two ears. It is not uncommon to find the infected stalks unusually large in diameter.

The symptoms just mentioned are often associated, singly or in combination, with severe conditions of the disease, and they are the ones that can readily be recognized without destroying the

[a]Unpublished data, Illinois State Natural History Survey.

plant. They are not, however, an infallible guide, for the conditions just mentioned may also at times be brought on by other causes, and furthermore, not all infected plants show these symtoms. At the time the plants are approaching maturity, some of the fibro-vascular bundles in the stalks of infected plants usually show a blackened condition (Fig. 39). Many plants that appear normal outwardly and develop a large-sized ear are infected and show the black bundle condition in the interior relatively late in the season. This condition is considered the surest symptom, but the stalks have to be cut open before examination can be made and furthermore there is a possibility that even this condition may at times be caused by other factors than the organism here mentioned.

FIG. 38.—MULTIPLE EAR DEVELOPMENT CAUSED BY CEPHALOSPORIUM INFECTION

In ordinary field corn this condition, together with considerable purple discoloration of the stalks and leaves, indicates that the plant probably is infected with *Cephalosporium acremonium* (black bundle disease). This disease, however, does not always cause multiple ears, nor are multiple ears always a sign of this disease.

Altho infection is systemic and starts in the early seedling stage, it does not seem to retard the vegetative development of the plant. The economic loss results from the check in grain production.

Cause. Black bundle disease here described is caused by *Cephalosporium acremonium* Corda, a fungus of the class Imperfecti. The spores are one-celled, averaging 4.5 by 1.35 microns in size.[89*] They are borne in groups at the ends of short stalks, as illustrated in Fig. 56. These groups or clusters of spores appear like a single spherical head under the 16-mm. objective of the microscope.

Seasonal Cycle of Parasite. As many infected plants bear full-sized ears with little or no external evidence of disease, these ears, altho they actually are infected, are often used for seed ears. This

FIG. 39.—A HEALTHY STALK, LEFT, AND THREE OTHERS INFECTED WITH BLACK BUNDLE DISEASE

The vascular bundles (strands that conduct the water and food thru the plant) are nearly white when in a healthy condition, but in advanced stages of *Cephalosporium acremonium* infection they become dark. This condition can be seen when the stalk is cut obliquely, as here shown.

infected seed in turn is apt to produce infected plants. The infection passes up the vascular system of the plant. In severe cases barren plants are produced, but when the infection is light, more infected ears are again ready for harvest. It is probable that infection may also take place from the soil.

Environmental factors are probably of considerable importance in determining seedling infection and disease development. Sometimes seed especially selected for a high percentage of Cephalosporium infection will show relatively little of this disease in the resulting crop, while at times the best nearly disease-free seed produces some plants showing symptoms of the disease.

Control Measures. It is well to avoid plants with reddish-purple colorations when making plant selections (page 28). Careful attention to the points enumerated under ear selections (page 32) is of considerable value.[46, 89*] To a certain extent the disease can be recognized when making the germination test (page 143) and badly diseased ears can be further discarded. However, not all infected ears can be avoided by these methods, especially when the selections are made on a commercial scale. Seed treatments, in the tests so far, have given only partial control of this disease. Crop rotation should be practiced.

BACTERIAL WILT
(Stewart's Disease)

Importance. Bacterial wilt occurs on sweet, flint, flour and dent corn, but it is in sweet corn that the greatest losses occur. It is of comparatively little importance in dent corn. Early maturing varieties of sweet corn are the most susceptible. Severe losses often occur in the Golden Bantam and Cory varieties. The later varieties, such as Zig Zag Evergreen, Stowell's Evergreen, and Country Gentleman, have been found to be more resistant. Rand and Cash[87*] say: "An arrangement of varieties according to time of maturity coincides almost exactly with an arrangement according to percentage of wilt development." Where early varieties are used, half the crop is sometimes lost from attacks by this disease.

Symptoms. Sweet corn plants show symptoms and are apt to die in all stages of development. Some infected plants succumb when only a few inches or a foot in height, while others live to produce good-sized ears. In young plants the leaves become limp, showing a typical wilted condition (Fig. 40).

At tasseling time the tassels of infected plants often develop prematurely and are nearly white in color.[100*] Many infected plants at this time are stunted, some being only half as large as the healthy plants. A gradual dying and drying out of the leaves takes place, progressing from the base of the stem upwards. Dying occurs from the tips of the leaves downward and from the margins inward. This may occur with or without a conspicuous previous wilting of the foliage. The rapidity with which wilting and dying take place in infected plants is in proportion to the amount of rainfall during that period.[99]* Altho wet weather will hold back the wilt symptoms, thus allowing the infected plants to make better

FIG. 40.—BACTERIAL WILT OF SWEET CORN

The hill at the left shows severe infection. Bacterial wilt causes great losses in the early varieties of sweet corn. It also occurs in dent corn, but is not of so much importance in that crop, and the wilted condition is not so likely to develop. (Reprinted from Ill. Sta. Bul. 255.)

growth, yet wet weather at the time of planting the seed tends to produce a high percentage of wilt.

The surest diagnosis of bacterial wilt in sweet corn can be made by cutting across the lower part of the stem after wilting or dying symptoms are pronounced on the leaves but while the stem is still a normal green and shows no indication of collapsing. In a few minutes after the stem is cut, small droplets of the yellow bacterial slime ooze out of the vascular bundles.[104*] If the point of a pencil or other object is touched to one of these droplets and then pulled away, the slime can be stretched out some distance, forming a fine thread. In advanced cases the bundles themselves turn brown.

In dent corn this ooze is not so evident, and rarely do typical wilt symptoms occur. The principal effect is a reduction in yield. Because the symptoms are not so evident, more of the disease may be present in dent corn than is ordinarily thought to be.

Cause. This disease is caused by a bacterium, *Aplanobacter stewarti* (E.F.S.) McC. It is rod-shaped (Fig. 2, *a*), non-motile, yellow, and slow growing. It retains its vitality and its virulence possibly for several years; drying out causes no injury.

Manner of Infection. Bacterial wilt may develop from infected seed and may also occur from bites of insects that carry the infection. There is experimental evidence to show that the beetle of the southern corn root worm spreads the disease when the corn is young. A little later in the season flea beetles spread the disease from plant to plant.[88*] Infection directly from the soil has not yet been demonstrated. The seed may become infected in two ways: bacteria may enter by way of the cob thru the vascular system, or may ooze out of the stomata of the husks and thus besmear the kernels.

This is a typical vascular disease, the bacteria being especially numerous in the vascular bundles of the infected plants. Nevertheless, bacteria may also enter thru the parenchyma, as by way of the stomata, and in the later stages pockets are formed containing numerous bacteria in the parenchyma, or pith, alongside the vascular elements.

Control. The use of resistant, that is, late varieties of sweet corn is an important consideration where such varieties can be used to advantage. Planting in wet soil or planting late, when the soil is warm, aggravates the disease.[99*] The majority of infections in the field possibly do not come directly from the seed but are transmitted by insects.[88*] After feeding on an infected plant, insects carry the bacteria to other plants. Seed treatments with organic mercury compounds have not been found effective in controlling wilt.[90*]

Reddy and Holbert[92*] found wide variation in the resistance and susceptibility of inbred strains of dent corn to injury from artificial inoculation with the bacterial wilt organism. They expressed the belief that early strains of wilt-resistant sweet corn could be developed.

COMMON SMUT

Importance. Common smut is well known to all corn growers and it is evident that it causes a certain amount of loss. Studies made by the Illinois State Natural History Survey[105*] during the years 1922 to 1927 show variations in the prevalence of the disease from year to year. Two hundred ninety-nine fields examined during this six-year period showed 3.9 percent of the plants affected with smut galls on the stalk or ear; smut infections on leaves or tassels were not included in the figure. One-third of the 3.9 percent produced no ears. The other two-thirds naturally suffered more or less loss in yield. It seems evident, therefore, that the average annual loss in yield of grain during this period was at least 2 percent. Similar data for the years 1917 to 1923[107*] placed the loss in yield at 2.3 percent.

Symptoms. Corn smut may occur on any of the above-ground parts of the plant. Fig. 41 illustrates smut on leaf, stalk, tassel, and ear. The leaves are the first to be attacked in any season. Next in order are tassels, ears, and stalks. The swellings are irregular and vary in size from that of a pea to a large double fist. At first these swellings are white in the interior. They are composed largely of fungus mycelium, altho corn tissue is also distributed thruout the smut gall. Later on, the white mycelium is converted into the black smut spores. The smut galls are covered with a glistening white membrane. As the smut matures, the membrane becomes thinner and thinner until it finally breaks. The millions of tiny black smut spores are then exposed and are ready to be blown about by the wind.

Cause. The common corn smut is caused by *Ustilago zeae,* (Beckm.) Unger. This is a fungus of the class Basidiomycetes. The black spores produced in the smut gall are rough on the exterior and average 8 to 11 microns in diameter (Fig. 30). When these spores germinate, they produce only a short sprout (promycelium) microscopic in size. On this sprout a number of spores, known as sporidia or conidia, are produced. These are colorless and

FIG. 41.—COMMON SMUT ON LEAF (A), ON TASSEL (B), ON STALK (C) AND ON EAR (D)

Common smut may occur on any of the above-ground parts of the corn plant. It attacks only corn. The spores are carried to the plant by the air; they are not seed-borne, as are the smuts of the small grains.

somewhat smaller than the black spores. This smut attacks only the corn plant. Several physiologic forms are known.[7, 102*]

Seasonal Cycle of Parasite. The smut galls disintegrate during the late summer and autumn and the smut spores become scattered on the ground. They overwinter in soil, manure, and compost. When summer temperatures recur, together with sufficient dampness, the spores germinate and give rise to a crop of conidia. These in turn are carried by air currents to the cornfields and cause more smut infection. Only young, succulent tissue is subject to infection in the absence of wounds. Thus leaves, tassels, and ears become infected while they are in the process of development. Stalk infection takes place from spores carried behind the leaf sheath by water. From the ear on down there is a small, more-or-less rudimentary bud at each node behind each leaf sheath. This bud becomes the point of infection, and thus the stalk is invaded. This invasion reduces the sugar content of the plant,[51*] and this in turn interferes with ear development. Wounds from hail or farm implements often open the way for infection.

There is some difference of opinion as to whether wet or dry weather favors the disease. Güssow and Connors[31*] state, "Dry weather holds the disease in check, but wet weather favors its rapid spread." Several previous writers have come to similar conclusions. Potter and Melchers,[85*] on the other hand, observe that corn smut is not so destructive in the humid eastern section of the United States as it is on the hot and dry plains of Kansas and Nebraska. In Illinois slightly more smut was found in the western half of the state, where there is a slightly greater summer rainfall (Fig. 5).

Unlike the smuts of small grains, this smut is not seed-borne and is not systemic; that is, the disease does not start with the seedling and develop within the growing plant. Each smut gall is due to a local infection from spores carried to the plant by air currents. Seed treatment, therefore, can be of no help in control.

Control. It has been demonstrated by a number of investigators[29, 35, 46, 52, 53, 59, 83*] that resistance and susceptibility to corn smut is inherited. This fact is important, for it offers the best opportunity for controlling the disease even tho the situation is complicated by the existence of a number of physiologic forms of the fungus.[7, 102*]

In open-pollinated corn, plant selection is the most important consideration in reducing losses from this disease. Those who have followed this practice for several years, taking seed ears only from plants that are free from smut and are desirable from the standpoint of other considerations also (page 28) are having, for the most part, very little loss from smut. Thoro protection of the ear by the husks has been shown to be of value in preventing ear infection.[72*] Crop rotation and sanitation also are of importance, since by such means the amount of inoculum in the cornfield may be reduced. It has been reported that spraying the plants with a fungicide has controlled the smut, but so far this method has been found impracticable. As stated above, seed treatment is of no help.

LEAFY ABNORMALITIES OF TASSELS AND EARS

Occasional fields have been found in Illinois in which some of the plants of dent corn have developed extensive leafy outgrowths in place of the normal structures of tassels and ears. This has been observed in several different seasons and in widely scattered parts of the state. In a cornfield observed in Douglas county in 1927, where the field had been used as a feedlot during the previous summer, these leafy abnormalities caused a loss of at least 60 percent in yield of grain. In most cases where this disease or disorder was observed, however, the actual loss in yield was comparatively slight. In a number of instances it was observed that the abnormalities occurred on the lowest part of the field.

The leafy abnormalities of the tassels were in some instances nearly as large as bunches of bananas (Fig. 42). Each floret was altered so that it produced a structure which superficially appeared like a young corn plant (Fig. 43). Very often the plants with such transformed tassels also exhibited a leafy branch in place of an ear, in some extreme cases the leafy branch being so extensive that the end touched the ground. A great deal of common smut was frequently found on the tender foliage of these abnormal growths.

The cause of this disorder has not been determined. Apparently *Sorosporium reilianum* sometimes causes leafy outgrowths of this sort instead of the spore masses known as head smut.[12, 93*] In some fields where these leafy abnormalities were observed in Illinois, a careful search for head smut was made but none was found. A number of Sclerospora species have been reported to be the cause of leafy malformations of the floral organs of maize, teosinte, and other graminaceous hosts.[115*] Some rare cases of apogamy (development of new plants nonsexually from parts that normally produce sex organs) have been observed in maize plants, presumably in

FIG. 42.—LEAFY ABNORMALITY OF THE CORN TASSEL

A large mass of leafy growth has developed in place of the normal tassel. The cause of this abnormality as observed in Illinois has not been determined.

the absence of disease.[9*] It is well known, furthermore, that there are many heritable abnormalities in corn, but apparently this particular abnormality is not caused by heritable factors.

FIG. 43.—PORTIONS OF AN ABNORMAL TASSEL SUCH AS SHOWN IN FIG. 42
In place of the normal floral organs, much larger vegetative growths resembling young corn plants have formed. The cross lines are one inch apart.

ROOT ROTS

GENERAL CONSIDERATIONS

In the earlier investigations the seedling diseases just described were classed under the general term "root rot." It was known that many plants are afflicted with a root rot thruout their life period (Fig. 44) but the cause had not been investigated, and even now the information on root rot of older plants is meager. It is becoming evident, however, that rots due to seed infection are confined to an area rather close to the seed, and that the more widespread root rot is not caused by seed infection but rather by organisms occurring in the soil. It is well to make a distinction, therefore, between seedling diseases and a rot that involves the major part of the root system.

It seems apparent from the data obtained in one of the field tests that the plowing under of a badly scabbed crop of spring wheat caused a considerable decrease in the yield of the following

FIG. 44.—SUSCEPTIBILITY AND RESISTANCE TO ROOT ROT

Portions of two root systems, the one on the left having been damaged by root rot and the other showing practically no injury. (Reprinted from Ill. Sta. Bul. 255.)

corn crop.[67*] There is evidence to indicate that only the seminal root system, together with the mesocotyl, is susceptible to Gibberella infection, not only when infection is carried on the seed but also when infection occurs from the presence of the fungus in the soil. This conception does not change the economic significance of soil infestation with *Gibberella saubinetii,* but does help considerably toward an understanding of the root rot situation.

Recently a Pythium root rot has been described by several investigators.[3, 57, 111*] This causes a rot of the cauline root system.

The discovery has thrown considerable light on the corn root rot problem. Whether there are still other organisms that are able to cause an extensive root rot under good soil conditions remains to be determined.

PYTHIUM ROOT ROT

Importance. A Pythium fungus has been identified as causing root rot in Kentucky,[111*] Missouri,[3*] and Wisconsin.[57*] There is a great deal of root rot all over Illinois. This is most evident at the time the ears have reached the dent stage. Tests made with a specially designed pulling machine[48*] showed variations of 5 pounds to 700 pounds in the resistance of corn plants to a vertical stress which pulled them out of the ground. Such differences can be found in many fields. To a considerable extent these differences in root anchorage are due to differences in the natural development of the root system, but another very important factor in producing these variations would appear to be root rot. Many of the plants that pulled up easily were severely afflicted with root rot. Injuries due to such rot are severe and very extensive in the state, causing a general loss of at least 5 percent in yield of grain and probably considerably more. To what extent this loss in Illinois is due to Pythium has not been determined. It can only be said that so far, in soil of well-balanced fertility, Pythium is the only fungus that has been definitely determined as causing a rot of the adventitious root system, and it has been isolated from rotted roots collected in several parts of the state.

Symptoms. Quoting Johann, Holbert, and Dickson:[57*] "Pythium injury to corn may be manifest as (1) a rot of the embryo, preventing germination; (2) as a seedling blight after emergence; or (3) as a root rot that tends to reduce the size, vigor, and yield of the maturing plant." It was found that germination may be prevented by attack of the fungus at low temperatures—54° to 60° F.—particularly in wet soils; also that when growth takes place, a soft rot of the seedling root system may develop. "In such plants subsequent invasion of the mesocotyl occurs and seedling blight results. Or, a mild root rot may occur, not severe enough to kill the seedling, yet resulting in a reduction in size and vigor, due to the decreased root surface and perhaps to the effect of toxins produced in the invaded cortical areas."

Pythium does not commonly attack the mesocotyl and in that respect is unlike Diplodia and Gibberella. Altho the roots may be severely rotted, the mesocotyl usually remains sound. The fine-branching rootlets are the first to be attacked, and from those parts the fungus travels inward to the large roots. In digging up plants, the infected parts are easily broken off and left behind, so that the presence of the fungus may be difficult to determine.

Valleau, Karruker, and Johnson[111*] state: "About the time of ear formation in Kentucky, it is difficult, on corn grown in some long-cultivated fields, to find more than a few live roots, the plants appearing to subsist on moisture and plant food drawn from the soil largely thru dead roots and new roots thrown out after rainy periods." From their experiments they conclude that this rot is caused by a species of Pythium.

Branstetter[3*] in Missouri found that evidences of corn root rot do not appear until about the time of ear formation. He says, "At this stage the roots begin to rot badly, so that in a short time a fully developed stalk may be rather easily lifted out of the soil, all of the main roots being rotted off at the depth of three or four inches." He found this condition rather general in Missouri. He also found Pythium in the rotted roots and concluded that the rot was probably caused primarily by this fungus.

Cause. Pythium root rot is caused by *Pythium arrhenomanes* Drech., a fungus of the class Phycomycetes. It produces oogonia, antheridia, conidia, and sporangia. The oogonium (female cell) is fertilized by an antheridium (male cell) and the result is a heavy walled oospore. These oospores often are found in diseased corn roots. They measure 20 to 30 microns in diameter. The conidia are somewhat similar in appearance but are produced without fertilization. The sporangia produce numerous zoospores which are able to swim about in water. They are short lived. Some other Pythium species may also be involved.[26*]

Life Cycle of Parasite. The species of Pythium causing corn root rot appears to be a parasite that lives only in the soil. It is not carried on the seed. It was found that the same species that affect corn also attack the roots of sugar cane, sorghum, wheat, and oats, but legumes are not affected by them.[26*]

Control Measures. Crop rotation (page 19) seems to be of considerable importance in holding the disease in check. There also is strong indication that some strains are more resistant than others.[57*] Plant selection (page 28), with good care to picking ears only from well-rooted, apparently sound plants, should therefore tend toward more general resistance to the disease. Information on the relation of water drainage and nutritional factors to the development of the disease is needed.

MALNUTRITIONAL ROOT ROT

In many localities in Illinois a severe condition of root rot and sometimes a stalk rot has been observed. These areas often are limited to a few acres in size altho in some cases much larger regions are involved. In most instances the application of potash salts or coarse manures has remedied the situation. The plants usually start growth fairly well. In severe cases growth may be checked when waist-high. Owing to root rot, and sometimes stalk rot, many plants fall to the ground during August. In less-severe cases the plants may grow to full size but the ears fail to develop and fill out properly. It was concluded by Sears[97*] that the abnormal growth of corn on these soils is due, not to a single condition, but to a combination of factors, chief among which is a lack of available potassium in combination with a concentration of nitrate nitrogen, which is harmful. This conclusion is based on the assumption that a favorable physiological balance is desirable, particularly with reference to potassium and nitrate nitrogen.

Under unbalanced nutritional conditions of the soil, Hoffer and Carr[39*] and Hoffer and Trost[40*] found that iron and aluminum compounds accumulated in the cornstalks. They state that these accumulations are toxic to the plants and render the roots especially susceptible to the development of root rot. They found that deficiencies of lime, phosphate, and potassium were especially prone to cause these disturbances. They also found that there was a genetic difference in individual plants in resistance and susceptibility to metal accumulations and the accompanying root rot. In a later article by Hoffer[38*] directions for making chemical tests to determine plant-food needs were given.

In a number of fields in southern Illinois in 1928 and 1929, where unusually severe root rot took place so that the plants were decidedly underdeveloped and many had fallen to the ground, chemical tests of the stalks were made by the senior writer. These tests showed an excess of nitrates in the internodes, together with heavy iron deposits at the nodes. This would indicate a potassium deficiency according to the Hoffer test. In a field adjacent to one of these badly diseased fields, where the corn was tall and standing up well, the stalks gave a similar test. Here too the corn may have been suffering to some extent from metal poisoning, but certainly not to the extent that occurred in the badly diseased field. It was found that no sweet-clover crop had been turned under in this adjacent field, and therefore it evidently was not so rich in nitrogen and consequently not so much out of balance, altho the stalks showed an excess of nitrates and iron accumulation. The chemical test alone does not seem to be precise enough to predict the degree of mineral deficiency of the soil, but the general appearance of the plant must also be taken into consideration. This observation is in accordance with statements made by Hoffer.[38]*

STALK ROTS

BACTERIAL STALK ROT

Importance. Illinois appears to be near the northern limit for the development of bacterial stalk rot. Only rarely has it been found to cause an appreciable loss in any fields in the state. In Arkansas, however, it was found to be at times the most destructive disease of corn, losses as high as 30 percent having been observed.[96]* So far the disease has not been found in the northern part of Illinois, McLean and Hancock counties being the northernmost counties in which it has been observed. Moist, warm weather is necessary for the development of this disease. In addition to occurring on field corn, the disease has also been found on Golden Bantam, Stowell's Evergreen, and Country Gentleman sweet corn.

Symptoms. Infection takes place in young as well as in older plants. The rot occurs at the lower nodes and in advanced stages may readily cause the stalks to fall over. Infection passes up and down the stalk to a very limited extent only. At times the rot involves the outer circumference of the stalk, causing a dark soft decay there (Fig. 45), while at other times the rotted area is principally in the interior of the stalk, so that only a shell remains. In either case the stalk is apt to fall. Most of the infections usually escape notice because they are not so severe, involving only a small area of the diameter of the stalk. In addition to the rotting of the stalk a light to dark-brown rotting of the leaf sheath may take place, the rot usually beginning in the parts that join the stem.

After such a rot has developed, the blades of these leaves may become yellow and die.

Cause. The disease is caused by a rod-shaped non-motile bacterium (Fig. 2, *a*) named *Phytomonas* (Pseudomonas) *dissolvens*

FIG. 45.—BACTERIAL STALK ROT OF CORN

This disease occurs in local areas on the lower portion of the cornstalk. When infection is severe, the stalk is very apt to fall. (Courtesy H. R. Rosen, Arkansas Agricultural Experiment Station.)

Rosen. It is somewhat sensitive to drying, freezing, and sunlight. Growth in culture is fairly rapid. The colonies are white in color.

Seasonal Cycle of Parasite. Just how the infection is first introduced into a field, how the bacteria are able to live thru the winter, and how long they may remain alive in the soil or corn refuse and be able to cause new infections has not been determined. Rosen[96*] has made the suggestion that the bacteria may possibly be carried on the seed and also that they may overwinter in the bases of the old corn plants. Even if the corn is cut off, much of the infected material would remain in the field because the disease very often occurs close to the soil level of the stalk. Infection of the new crop takes place readily only when the weather is very damp and when the temperature is 85° F. or over. So far, this bacterium has been found to be pathogenic only on corn. Infections may take place thru stomata, insect injuries, and cracks in the stalks occurring where the brace roots push thru.[96*]

Control. As the disease is ordinarily of no economic importance in Illinois, no attention to control measures has been given. Crop rotation (see page 19) is probably the best recommendation wherever the disease is of consequence.

DIPLODIA STALK ROT

Importance. By the time the corn is in the dent stage, many stalks may be infected with *Diplodia zeae.* Most of these stalks are green. This rot accounts for many of the broken stalks, the amount of breaking depending in part on the severity of the winds. This breaking of the stalks often allows the ears to rest on the ground, where they may rot. Husking them is made difficult. Even where no breaking occurs, a considerable rotting of the stalk would check food translocation and therefore hinder the full development of the ear. By the last part of September a considerable number of dead stalks may be noticed in the fields with numerous Diplodia pycnidia scattered over the lower nodes (Fig. 46). Whether such stalks were killed by the stalk infection, or whether they died from other causes, is not clear. The dying plants are easily invaded by Diplodia, the pycnidia of which may be found on most pieces of old cornstalks in the fields in the spring or summer. In addition, many of the shanks are attacked. A considerable number of these break, thus inhibiting the final maturing processes of the ear. It is evident from the foregoing that Diplodia stalk rot is a real economic factor, but in the absence of carefully controlled experiments to determine this loss, and as many of the losses are indirect, it is almost impossible to make a percentage estimate that would mean anything. It may be said, however, that the loss in yield due to Diplodia and other stalk rots is at least 2 percent.

Symptoms. Practically no Diplodia stalk rot takes place until the tassels are full-sized and ear development has begun. Up to this time the leaf sheaths have clasped the stems very closely, but now growth in size of the plant (excepting the ear) practically ceases and the leaf sheaths begin to loosen. Infection of the stalk

FIG. 46.—DIPLODIA PYCNIDIA ON DEAD CORNSTALKS

The larger part of each pycnidium is buried in the tissue, only the point coming to the surface. These Pycnidia can be found in the fall on plants that have died early, but on other stalks they are not so apt to develop until the following season. Each pycnidium contains many spores, which are dispersed by the air when mature and reinfect the next corn crop.

occurs in the moist region within the leaf sheath and has been observed to occur largely thru the axillary bud (Fig. 10) and thru the tissues of the leaf sheaths as they become continuous with the stalk tissues. By the end of August rotted areas can usually be found by splitting open the lower four or five nodes of the stalks.

A month later these areas are much more extensive, extending some distance up and down from the nodes. The rot is brown in color. This browning also appears on the exterior of the stalk. Sometimes the rots originating at consecutive nodes overlap in the internode, but rarely does the rot starting at one node progress thru the internode until it involves the next node, except at the base of the stalk and in the shank, where the nodes are very close together. Pycnidia are not produced until the affected part of the plant is dead. These rots are responsible for many broken shanks and fallen stalks.[21*]

When Diplodia inoculum is present, this kind of stalk rot may be worse when the plants are grown on soil having a high level of productivity than on less-productive soil. The use of corn selections resistant to this rot is the most effective means of control. In strains having high resistance and planted on well-managed soil, there should be little or no trouble from Diplodia stalk rot.

For *cause, seasonal cycle,* and further discussion of *control,* see page 51.

OTHER STALK ROTS AND INJURIES

In addition to finding Diplodia as a common cause of stalk rot, *Gibberella saubinetii, Basisporium gallarum,* and a Fusarium species have frequently been isolated from the infected nodes of cornstalks by Durrell[21*] in Iowa. Apparently all these fungi have a pronounced effect in reducing the breaking strength of the stalks. The common ear rot fungus *Fusarium moniliforme* seems not to have been found in the infected corn nodes used in Durrell's experiment, but Gibberella was abundant in his isolations made in 1923. Judging from the prevalence of Gibberella perithecia on old cornstalks left out in the field over winter and examined the next summer (Fig. 47), the extent of Gibberella stalk infection varies widely from season to season. This is in accordance with the wide seasonal variations in severity of Gibberella ear rot and the scab of small grains.

It has been reported that brown spot infection of the stalks, especially at the nodes, sometimes is the cause of considerable stalk breaking in Kansas.[58*] Stalk breaking from this cause has not been observed to any marked degree in Illinois.

Hoffer and Carr[39*] state that "in a large majority of cases the common *Fusarium moniliforme* Shel., *Gibberella saubinetii* (Mont.)

Sacc., *Penicillium* sp., *Rhizopus* sp., an unidentified white bacterium, and others are found to be present, especially if the nodal tissues in the lower parts of the stalk are cultured." They also found, however, that in many cases no organism could be isolated from brownish-purple, discolored nodal tissues. They concluded that this discoloration may often result from an accumulation of iron and aluminum compounds in the stalk due to unbalanced soil nutritional

FIG. 47.—GIBBERELLA PERITHECIA ON AN OLD CORNSTALK

Unlike the Diplodia fruiting bodies (Fig. 46), these perithecia are not imbedded in the stalk but occur on the outside of it. In some seasons these are very common at wheat-heading time on old cornstalks left lying on the ground over winter. The spores are carried by the air and infect the small grains and corn when the weather conditions are favorable for infection to take place.

conditions. They also concluded that infection with the organisms they mentioned may possibly be limited to cornstalks previously injured or predisposed to infection by the iron or aluminum compounds.

Porter,[84]* in making isolations from cornstalks collected over an area of 20 different states, found that the most prevalent fungi isolated from the nodes occurred in the following descending order: *Mucor* spp., *Fusarium* spp., *Fusarium moniliforme, Penicillium* spp., *Rhizopus nigricans, Aspergillus niger* group, yeasts, *Alternaria* spp., *Diplodia zeae.* All these organisms occurred in more than 1 percent of the isolations; others occurred less frequently. In addition, several types of bacteria were frequently found. Porter concluded that most of these organisms are purely saprophytic, entering the nodes only after they have previously been killed by accumulations of toxic metallic compounds due to faulty nutritional conditions.

It seems to be a fact that under some circumstances nodes or stalks die prematurely as a result of toxic conditions, and after death the tissues are easily entered by saprophytic organisms. On the other hand, many immature green stalks without internal nodal discolorations are infected at one or several nodes. It does not seem likely that this condition could obtain without the action of a parasitic organism.

The experience of the writers has been that when nodal discolorations are caused by faulty nutrition (metal accumulation), all the lower nodes are more or less uniformly discolored and the discoloration in each node is fairly uniform in cross-section. Fungus infections or rots, on the other hand, in the absence of the abnormal physiologic discolorations just mentioned, occur irregularly on the stalks. One or several nodes may be badly discolored while others appear healthy. Furthermore, one side of a node may be badly discolored, the rot extending several inches up and down the stalk, while little rot may occur on the opposite side of the node, the rot being very irregular in cross-sections of the stalk.

Another kind of stalk injury that is now receiving attention is caused by low temperatures.[42, 43, 44*] Death of the leaves, altho sometimes a vital factor, is not of so much significance as death of the stalk. When the stalk dies, translocation of food stops, and unless the ear is mature at the time, it must remain immature. The ear will dry out and will sometimes present the superficial appearance of maturity, but a close inspection is likely to show that it lacks luster, is not as horny as it should be, the kernels are not fully developed at the tip end (Fig. 14), and that it possesses other characteristics associated with immaturity, such as susceptibility to certain diseases. Such ears are lighter in weight and thus the yield is reduced. In more extreme cases the ears are chaffy.[41*]

Stalks and shanks that are killed by low temperatures while in an immature, sappy condition are quickly overrun and penetrated by various saprophytic organisms.[44*] The breaking strength of the stalks is thus reduced and such corn is very apt to go down. Organisms entering the shank are apt to enter the ear also.

The temperature need not be down to freezing to cause injury. Quoting from Holbert and Burlison:[44*] "Some strains are injured by a succession of cool nights during which the temperature drops only to 50° or 40° F. Other strains are killed by a few hours of exposure to temperatures around 40°. Altho some strains may not actually be killed by such temperatures, their maturing often may be slowed down sufficiently to reduce the quality of the grain. Corn from plants killed prematurely by cold not only is inferior in quality but also is more susceptible to ear rots." It is stated also that some recombinations of inbred strains apparently were not injured by exposure to a temperature of 28° F. for several hours, and that open-pollinated varieties have been improved in their resistance to cold by continuous selection toward that goal.

LEAF DISEASES AND DEFECTS

RUST

Importance. Ordinarily corn rust causes only very slight injury to dent corn, but occasionally heavy infections have been observed, especially on certain strains. In one investigation[113*] it was found that sweet corn was the most susceptible. Next in order were flint, flour, dent, and pop corn, the latter being the most resistant. It is known also that there are considerable differences in resistance and susceptibility within strains of these subspecies.

Symptoms. Rusty spots develop on the leaf blades (Fig. 48). These first appear as small, elongated blisters. The epidermis over these blisters soon breaks and the brown spores are taken up by air currents and are spread to other plants. As the epidermis breaks, the spots (sori) become rather irregular in outline. In the summer the sori are rusty brown in color, but later in the fall as the winter spores (teliospores) develop, these sori become nearly black. Rust will hardly be confused with any other disease except "brown spot," which is described next.

Cause. This rust is caused by *Puccinia sorghi* Schw., a fungus of the class Basidiomycetes. It has four spore forms. The pycniospores and aeciospores are found only on certain species of Oxalis (wood sorrel, lady's sorrel, etc.) while the urediniospores and teliospores (Fig. 30) are found only on corn. The urediniospores are dark brown in color, one-celled, nearly spherical, and measure 23 to 30 by 22 to 26 microns in size. The teliospores are a very dark brown, usually are two-celled, and measure 28 to 45 by 12 to 17 microns. The stalks on which the teliospores are borne often stay with the spores when they become detached. Several physiologic forms of the rust are known.[75, 102*]

Seasonal Cycle of Parasite. This rust in some respects is similar to the black stem rust of small grains. The two stages on Oxalis correspond to those on the barberry, and the two stages on the corn

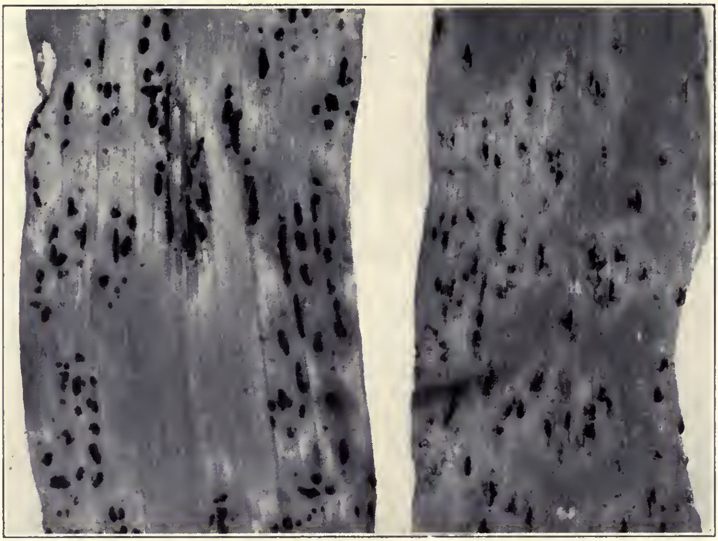


FIG. 48.—CORN RUST ON LEAF BLADES

In summer the spots of corn rust are rusty brown. The epidermis breaks open as the spores mature, and in the fall the spots become nearly black. This rust is distinct from the rusts of the small grains, and so does not cross over from one crop to the other. (Courtesy E. B. Mains, U. S. Dept. of Agriculture and Purdue University Agricultural Experiment Station.)

plant correspond to those on the small grains. The pycniospores of the corn rust fungus doubtless function in initiating the production of aeciospores, which are borne on Oxalis. This conclusion is based on the recent discovery of the function of the pycniospores of black stem rust of small grains. The aeciospores, borne on Oxalis, are able to infect only corn plants. After the corn becomes infected, the rusty brown urediniospores are produced. These also are able to infect corn only and serve to spread the disease in the cornfields. Late in the season the very dark-colored teliospores are formed.

These cannot infect the corn, but in the spring they germinate on the old leaves on the ground and produce another crop of spores, the sporidia. These infect only Oxalis, and thus the cycle is completed.

In rusts, the teliospores are the typical overwintering spores, while the urediniospores are produced in large numbers in the summer and serve to spread the disease, but they are not so hardy and usually do not overwinter well in northern climates. To what extent the rust on corn is first started in the season by overwintered urediniospores from the previous corn crop or by aeciospores from Oxalis has not been determined. Some pathologists, because they could not find infected Oxalis, have assumed that it is caused primarily by overwintered urediniospores. It has been shown, however, in some experiments that in Wisconsin[113*] and Iowa[101*] urediniospores do not remain alive overwinter, and it has been observed that sometimes aeciospores can be found rather readily on Oxalis.

Control. Altho rust ordinarily does not cause any commercial loss in dent corn in Illinois, the writers have observed a few commercial fields in which there was considerable injury to the leaves and probably a reduction in yield as a result of rust infection.

In developing inbred and crossbred strains of corn, individual plants, progenies, and occasional crosses may occur that are very susceptible to rust. Other plants and progenies, on the other hand, are practically free from rust infection in the same field under the same conditions.

The selection and breeding of strains of corn highly resistant to rust is the most effective method for the control of this disease.

BROWN SPOT

Importance. Brown spot causes considerable loss in the southern states, but becomes of less importance northward. Northern Illinois is about the northern limit of its distribution. Only rarely has the disease been found to be of importance in this state. All varieties of corn, including sweet and pop corn, are susceptible.[110*]

Symptoms. The disease can be recognized by the circular brown blisters produced on leaf blades, leaf sheaths (Fig. 49), and stalks. It occurs primarily on the lower half of the plant. In Illinois the blisters have been observed principally on the inner surface of the leaf sheaths, on the lower portion of the blades, and on the nodes of the stalk. Infected sheaths are more or less discolored but care must be taken not to confuse this disease with the purple sheath disease described on page 105. On the blades these brown spots are sometimes taken for rust, but the rust spots are more irregular in shape and occur on the upper blades as abundantly as on the lower. Furthermore the rust spots are more evenly distributed over the leaf surface and the rust pustules break the leaf surface conspicuously while those of the brown spot do not. Occasionally brown spot may be the cause of considerable stalk breaking.[58*]

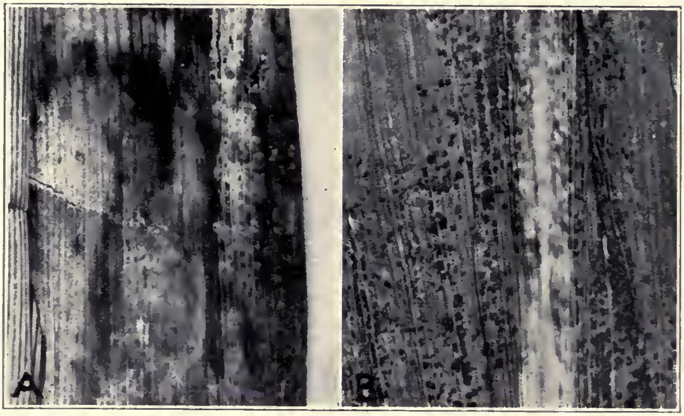


FIG. 49.—BROWN SPOT ON A LEAF SHEATH AND A LEAF BLADE

These spots are brown in color but they are more rounded than those caused by rust. They occur mostly on the leaf sheath (*A*) and lower end of the blade (*B*) and are covered by the epidermis as long as the plant is green.

Cause. Brown spot is caused by *Physoderma zeae-maydis* Shaw, a fungus of the class Chytridiales. The brown dust in the dark spots on the plant consists of many spore-like bodies which are zoosporangia. These are 18 to 24 by 20 to 30 microns in size and are dark brown in color. They resemble the urediniospores of corn rust somewhat. The zoosporangium is somewhat flattened on one side and this place is provided with a sort of lid. On germination this lid opens and a number of swarm spores come forth. These swim about rapidly for a time in the film of water which is necessary for germination.

Seasonal Cycle of Parasite. The zoosporangia overwinter in the corn refuse or soil, and in the following year they are carried to the new corn crop by wind, insects, water, or other agencies. After they have come in contact with the young corn plants, plenty of moisture and warm weather are necessary in order for them to germinate. After the swarm spores are liberated, they swim about for a while, then settle down on the host epidermis and produce a mycelium which penetrates the epidermis and thus causes infection. Germination does not take place at temperatures lower than 73° F.[110*] In addition to occurring on the various kinds of corn, this disease also occurs on teosinte.

Control. Occasionally a few inbred strains have been heavily infected with the brown spot disease in this state. But always there have been in contiguous rows other inbreds on which no evidence of the disease could be found. In case brown spot ever does become of economic importance in Illinois, undoubtedly resistant strains will be available or can be developed for the section in which they are needed.

PURPLE SHEATH SPOT

Importance. Altho the purple sheath spot disease occurs on nearly every corn plant grown under practical farming conditions, the actual damage done by it seems to be small.

Symptoms. A purplish, reddish, or brownish discoloration occurs on the leaf sheath after pollinating time. Typical cases are shown in Fig. 50. Altho the outer surface of the sheaths clearly shows this discoloration, the epidermis is smooth and intact. But when the leaf sheath is broken loose, it is seen that the inner surface presents a more-or-less corroded appearance. Ordinarily no fungus growth or fruiting bodies are noticeable with the naked eye. Where the sheaths are invaded by Diplodia, death of the infected portion often ensues and the spot or blotch then becomes a grayish color.[19*]

Cause. Most of this spotting is caused by so-called saprophytic organisms—fungi and bacteria.[19*] A considerable number are involved. This clearly demonstrates again that the term "saprophyte" is only a relative one, many of the organisms so named becoming parasitic only when conditions become favorable enough for the organism or unfavorable enough for the host. *Diplodia zeae*, a typical parasite, also is responsible for such spots.

FIG. 50.—PURPLE SHEATH SPOT DISEASE

The purple blotching characteristic of this disease is very common and is sometimes confused with the symptoms produced by "brown spot." These sheaths were from above the ear, but the disease may be even more severe on sheaths below the ear.

Manner of Infection. While the stalks are growing, the leaf sheaths clasp the stalk tightly and the inner surfaces of the sheaths are clean. At pollinating time, growth in height ceases and the leaf sheaths loosen, so that dead pollen falls behind the leaf sheaths, together with spores, dust, and organisms of various kinds. Important also is the fact that moisture accumulates in this region, so that ordinarily it is damp. Various organisms begin growth, first living saprophytically on the dead pollen, and apparently as they make vigorous saprophytic growth, enzymes are produced which work on the inner surface of the sheath, so that a collapse of the tissue takes place. Most of these organisms are not able to attack the stalk; Diplodia, however, is able to do so (see page 96).

Control. Wide variations in resistance and susceptibility to the purple sheath spot disease exist, not only in inbred and crossbred strains, but also to a lesser extent in open-pollinated strains. While some strains are very susceptible, almost every leaf sheath being badly affected, other strains are only very slightly affected. Selection and breeding for resistance to this disease has been found effective.

HELMINTHOSPORIUM LEAF BLIGHT

Importance. Usually leaf blight is of little importance, for under average Illinois conditions it attacks the leaves only after they are waning in vitality. Under certain weather conditions, however, the younger plants may be attacked and considerable loss result. Such a condition has been reported from the Atlantic coast region, where, in an unusual year, this disease caused the leaves in August and September to appear as tho they had been killed by frost. No such severe damage has as yet been noted in Illinois. The disease is common on sweet corn as well as on dent corn.

Symptoms. The disease ordinarily becomes evident by the first of September as elongated, straw-colored, dry blotches, especially on the lower leaves. At first these blotches are small, half an inch or less in length, but they enlarge rapidly. Several weeks later a large portion of each infected leaf may be involved (Fig. 51). By the time the blotches are several inches in length, it is stated by Drechsler,[17*] "a grayish, greenish efflorescence makes its appearance in the center of the withered area, becoming gradually more extensive with the continued enlargement of the latter. This efflorescence consists of the numerous fructifications of the fungus which . . . . are more readily perceived with the naked eye than the fructifications of the majority of the species of Helminthosporium developing on the foliage of grasses." This blight should not be confused with other types of "firing" due to genetic, nutritional, or moisture factors.

Cause. Corn leaf blight is caused by *Helminthosporium turcicum* Pass., a fungus of the class Imperfecti. By examining with a microscope the efflorescence appearing on the withered spots, it is seen that this consists of conidiophores and conidia, the conidiophores appearing in groups of 2 to 6 thru the openings of the stomata.[17*] The conidia are 1- to 8-septate, greenish to brownish yellow in color, and measure 45 to 132 by 15 to 25 microns in size.

FIG. 51.—HELMINTHOSPORIUM LEAF BLIGHT

These blotches are typical after the corn has reached the dent stage. The dark centers of the blotches are composed of the fruiting structures of the fungus. Ordinarily the disease does not become prominent until late in the season and it therefore causes only slight injury.

Seasonal Cycle of Parasite. Nothing is definitely known concerning the form or manner in which the fungus remains alive during the winter. It is assumed, however, that it overwinters on the old crop refuse, and that in the following season the spores are carried by wind or other agencies to the new corn crop. In addition to attacking corn, the disease also occurs on sorghum and probably on some grasses.

Control. Altho this disease ordinarily is of relatively little importance in Illinois, general control measures discussed earlier in this bulletin should help to reduce its prevalence.

HOLCUS BACTERIAL SPOT

Importance. Holcus bacterial spot seems to be of little importance on corn, altho it causes some injury to sorghum, sudan grass, and broom corn.

Symptoms. The spots appearing with this disease are circular, elliptical, and irregular in shape, usually not more than one-fourth inch in width. The center of the spot becomes light to medium brown in color and this region is surrounded by a darker border, reddish to dark brown on corn, but bright red on sorghum and sudan grass. On corn these spots have been observed principally on the lower leaves, and usually are more numerous towards the tip end. Infections have been noticed as early as the last week of June.[61*]

Cause. This disease is caused by a bacterium, *Bacterium holci* Kendrick. It is rod-shaped, has polar flagella (Fig. 2), is not readily killed by freezing or drying, but will not grow at a temperature above 95° F.[61*] The death point is higher.

Seasonal Cycle of Parasite. Indications are that the bacteria causing this disease are carried in or on the seed of sorghum, and that they probably also overwinter in the soil. It is believed that the infection is not carried on seed corn, but that the corn crop becomes infected either from bacteria in the soil or from infections on sorghum or other infected grasses. Wet weather favors infection.

Control. Sanitation, crop rotation, and breeding for resistance (pages 18 to 37) are recommended. The effect of seed treatment in eliminating the infection on sorghum seed has not been investigated.

LEAF FIRING

Most types of leaf firing become noticeable after the pollinating period, but certain types may occur even sooner. Often the upper leaves are affected principally, sometimes only the lower leaves, and sometimes the outer ends or the margins of all the leaves are dead. Firing may be fairly general in a field or only certain plants show distinct symptoms. In the former case the trouble may be due to lack of moisture or plant-food materials or to unbalanced nutritional conditions. A lack of potash or nitrogen in the soil is especially prone to cause firing. When only certain plants show firing, the trouble probably is due to disease infection or to heritable weaknesses in the functional capacities of the plant. A heritable defect sometimes called "top firing" is very striking. The upper leaves, as well as the tassel, die shortly after the tassel has emerged. This, as well as some other types of firing, may occur when an abundant supply of soil moisture and plant food is available. Proper soil management and careful selection of plants should in time tend to reduce greatly the number of plants susceptible to these disorders.

Another type of firing is caused by sun scald during excessively hot weather. This may occur while there is an abundant supply of soil moisture, but is hastened by drouthy conditions.

HERITABLE CHLOROPHYL DEFICIENCIES

There are a number of leaf spots and streaks which, in some cases, resemble diseased conditions but which in reality are heritable deficiencies. A considerable number of such deficiencies, the expression of which is controlled by separate genetic factors, have been described, but only a few that occur frequently in open-pollinated corn will be mentioned here. Such chlorophyl deficiencies can be found in ordinary open-pollinated corn.

Striped Leaves. At corn cultivating time or when going thru the cornfield later, once in a great while one may see a plant with striped leaves, the stripes being continuous and uniform thruout the length of the leaf. On second glance it will be noted that all the leaves of the plant are striped in the same manner. Such plants will occasionally be found even tho one has been very careful to pick the seed only from apparently normal, healthy plants. A number of distinctly different kinds of stripings are known and specific names have been assigned to them. There are wide stripes and narrow stripes and variations in color; normal green alternating with light green stripes, green alternating with yellow and green with white. Some plants are striped beginning with the first seedling leaf. Sometimes the seedlings appear normal in color and the stripes make their appearance one or two months later.

Spotted Leaves. Spotted leaves occur somewhat more frequently than striped leaves. A common type is shown in Fig. 52, *B* tho the spots may be either considerably larger or smaller than there shown. This defect has also been called "blotch leaf."[27*] The spots or blotches are yellow in color. They may be circular, oval, or irregular in outline. Sometimes they appear very like those caused by parasitic organisms on some other plants. They appear only after the plant has attained some size and then they develop rather suddenly on all the leaves of the affected plant.

Dying Between the Veins. This defect is distinct from the other two defects just mentioned. It makes its appearance later in the season, after pollinating time, and is more pronounced on the upper part of the plant than on the lower part. It occurs as disjointed stripes bounded by the leaf veins (Fig. 52, *A*). The tissue in these

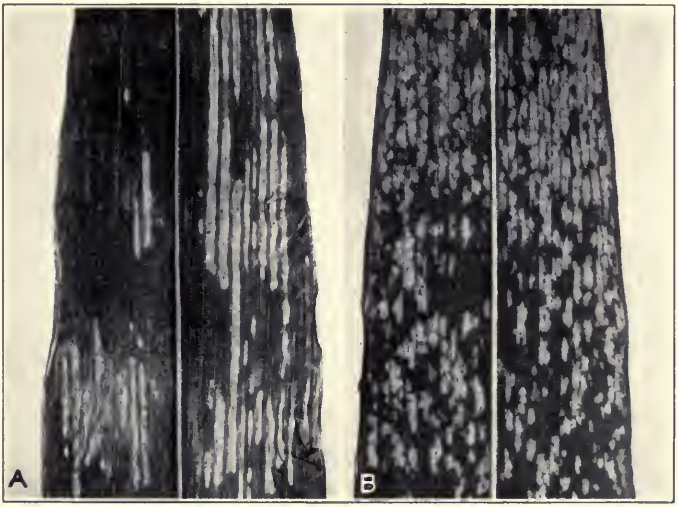


FIG. 52.—TWO TYPES OF HEREDITARY DEFECTS IN CORN LEAVES
(*A*) "Dying between the veins." These streaks appear after tasseling time and are most prominent on the upper half of the plant. (*B*) "Spotted leaf." This defect is rather uniform on all the leaves of the affected plant, and the tissue of the affected spots does not die so quickly as in *A*.

stripes soon dies, becoming straw colored, and later this dead tissue is apt to break, thus causing the leaf to appear riddled. Rapid dying of the abnormal tissue is not characteristic of the striped or spotted leaves previously discussed. Corn leaves that show the condition known as "dying between the veins" have been found to contain considerably more aluminum and iron than normal leaves.[37*] It seems, therefore, that this defect is an expression of a certain abnormal nutritional reaction within the plant which, in turn, is governed by heredity and possibly by soil conditions.

ROLLED LEAVES

When passing thru nearly any cornfield one can observe, at or before tasseling time, some plants with the upper leaves tightly rolled together (Fig. 53). Often the color of the rolled leaves is lighter green than normal. This is another inherited defect. In some types the symptoms are most pronounced on highly productive

Fig. 53.—Rolled Top, a Heritable Defect

This defect can be observed in most cornfields planted with open-pollinated strains.

soil. Sometimes it is impossible to unroll the leaves without tearing them, but in most instances the tassel finally pushes thru, and later these plants frequently cannot be distinguished from normal plants. No doubt there are a number of distinctly different types of rolled leaves. One type was described by Carver[6]* as "rolled" and another type was called by Kempton[60]* "adherent." The "rolled top" condition shown in Fig. 53 very likely is different from either one of the two just mentioned.

Control of Inherited Defects. Careful attention to the characteristics of the parent plant ("Plant Selection," page 28) when selecting the seed ears usually keeps the visible heritable defects down to a small percentage. Another method that promises to be more effective has been investigated by Woodworth, Winter, and Mumm. They self-pollinate many plants in a good, adapted strain of corn, and then plant part of each "selfed" ear in a performance test. The remnants of the desirable ears are then shelled and mixed. "The variety is thus reconstituted, as the self-fertilization eliminates considerable defective germ plasm and also weak, low-yielding types, thus leaving only the best material that was present in the variety at the start."[118*]

EAR ROTS AND OTHER EAR DEFECTS

GENERAL CONSIDERATIONS

Ear rots occur in practically every field and in every season, but there are great differences in the amount of damage done by them. Certain factors responsible for these differences, such as sanitation, crop rotation, soil fertility, seed selection, and strain of corn, are under the control of the farmer. Another important factor, the weather, cannot be controlled. On experiment fields of the Illinois Station it has been observed, for instance, that a strain of Northwestern Dent was particularly susceptible to Diplodia ear rot altho relatively resistant to Fusarium ear rot. The more "starchy" corn types are, as a rule, the most susceptible to the latter rot. The use of strains resistant to rots is a very important factor in control. Infections in the seed that is planted, however, has little or no direct influence on the amount of ear rot that will take place.[70*] In general, damp weather is favorable for ear rot.

Losses stated in this section as due to the ear rots described are based on data obtained by the senior writer from three rotation systems on the Experiment Station farm at Urbana over a period of six years, 1924 to 1929. Nearly all the corn was harvested and the separations were made during the month of November. The total loss from ear rot during this period was approximately 7½ percent. Good, adapted strains of Reid Yellow Dent were used in these tests, and it is believed that the farming practices followed probably were better than the average in the state. At this figure, the annual loss due to ear rot in the state as a whole is about 23 million bushels. But as most farmers pay less attention to sanitation and grow corn that has had less selection for disease resistance, the actual loss in the state probably is greater than this figure. Furthermore these figures indicate only the loss at harvest time and do not take into consideration the additional losses that may occur in the crib.

Some of the ear injuries caused by insects, mice, or defective heredity discussed in this section are indirectly related to disease. Corn so injured is more subject to certain infections when used for seed, and furthermore is more apt to deteriorate in storage than is uninjured grain, owing to activities of microorganisms when sufficient moisture is present.

Only the better known ear rots are discussed here; still other types are to be found, especially in frosted corn.

DIPLODIA EAR ROT

Importance. Further investigations have substantiated the findings of Burrill and Barrett[5*] in 1909 that Diplodia ear rot ordinarily is the most serious corn ear rot in Illinois.

When examining the ears in the fall of the year, Diplodia ear rot can be found in almost any field, but considerable variation in severity does occur as a result of differences in farm practices and weather conditions and to differences in the strains of corn used. Differences in resistance and susceptibility to the disease exist in both open-pollinated and inbred strains[46, 47*] (Fig. 54). The average annual loss from Diplodia ear rot on the plots above referred to was found to be about 3½ percent. Considerable increase in percentage of Diplodia ear rot has been observed on November 1 as compared with October 1. This agrees with data obtained in Ohio.[8*] Ear rot data, to be reliable, must therefore be obtained late in the season. Similarly, a farmer is likely to find less ear rot if he harvests his corn early, but the rots will probably continue to develop in the crib, so that the final result may be worse than if the corn had been left longer in the field. But when the ears can be dried promptly, harvesting immediately after maturity reduces the loss. Here also is a good argument for harvesting and drying seed corn as soon as it is fully mature.

As this fungus is active at a relatively low moisture content of the corn, down to about 22 percent, considerable additional loss may occur during mild weather after the corn is cribbed. Not only will the rot spread from rotted ears to adjacent sound ones, but many ears at harvest time carry the infection altho no rot has as yet developed at that time.

Symptoms. When infection takes place at pollinating time or in the milk stage, the infected ear becomes a shrunken, light-weight

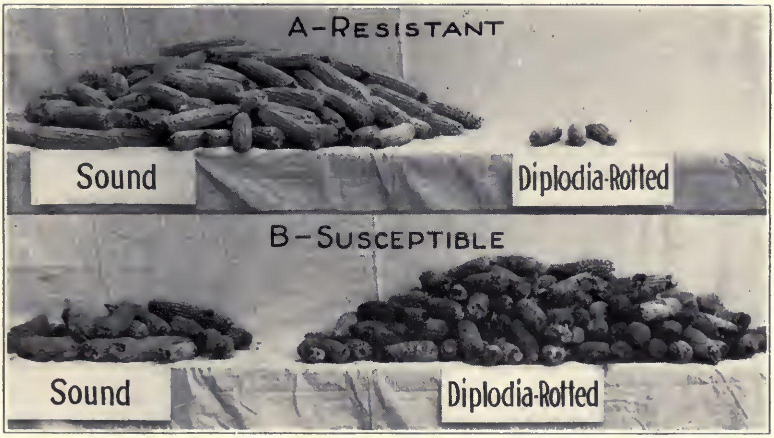


FIG. 54.—CORN STRAINS DIFFER WIDELY IN THEIR RESISTANCE TO EAR ROTS

Inbred line *A* has consistently shown marked resistance to Diplodia ear rot, while line *B* has proved very susceptible. Wide differences in resistance to Fusarium, Gibberella, and Basisporium ear rot have likewise been found in inbred lines. Differences in resistance to several of the ear rots have also been observed in open-pollinated strains.

mummy. The poorly developed rotted kernels are a dull brown in color and the grayish-white mycelium occupies the spaces between the kernels. This condition is illustrated in Plate II, ear *G*. Such mummies break very easily. Late in the fall, pycnidia can often be found when such ears are broken (Fig. 25).

The husks are tight on these ears, for the fungus has grown thru them and joined them tightly to the ear. As the ears develop past the milk stage, they may become infected from either the tip or the butt end, butt infections usually predominating. Altho the ears now are larger, they still may become totally worthless, like ear *E*, Plate II. Infection apparently started at the tip end of this

PLATE II

A, B Fusarium rotted ears.

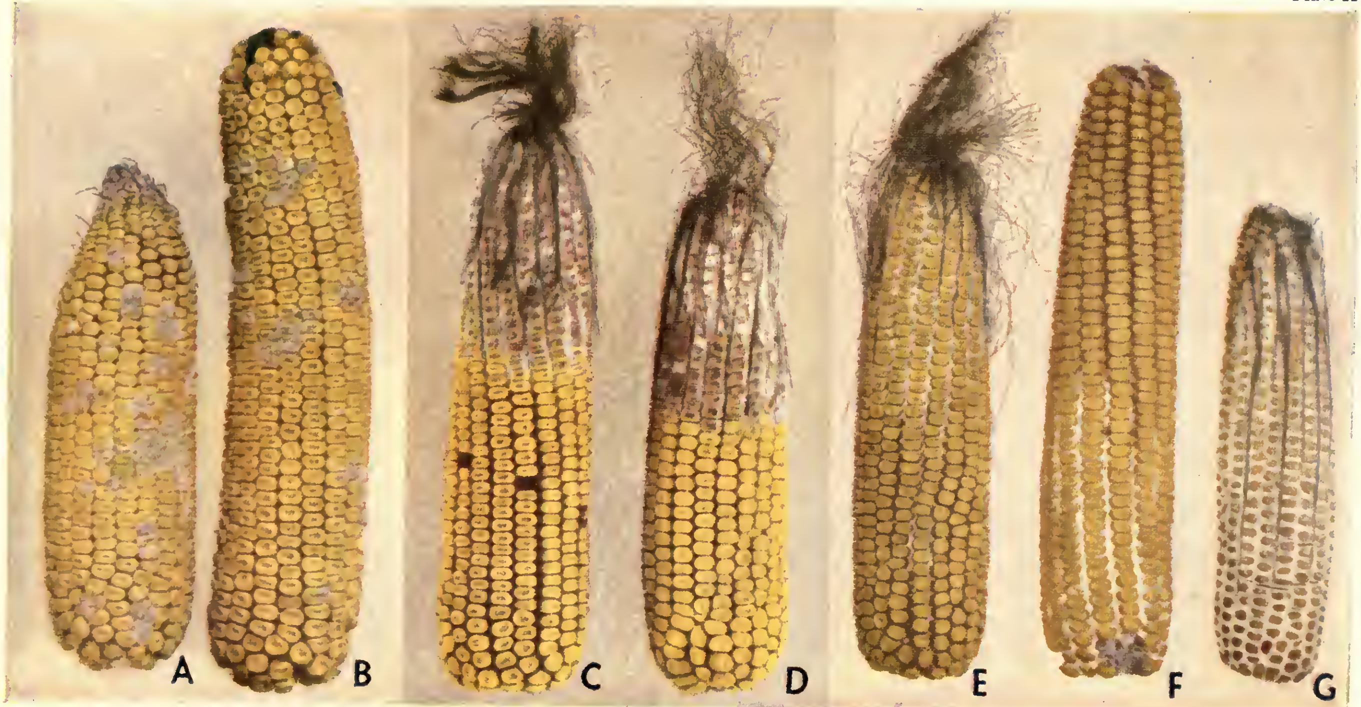
This rot, caused by *Fusarium moniliforme,* is one of the pink ear rots. The rotted kernels usually are scattered, involving sometimes only a few kernels and sometimes the major portion of the ear.

C, D Gibberella rotted ears.

This also is a pink rot but the infection begins characteristically at the tip of the ear and involves all the kernels as it progresses toward the butt end.

E, G Diplodia rotted ears.

This rot is caused by a white mold. In late infections it is seen primarily between the rows of kernels (*E, F*) progressing either from the tip downward or from the butt upward. When infection occurs early the ear is reduced to a brown mummy (*G*), very light in weight.


A
B
C
D
E
F
G

ear and a close examination shows the white mycelium extending down to the butt between all the rows. Infection started at the butt end of ear *F*, and altho that end is badly rotted, the damage does not extend the full length of the ear. In many cases, especially where the rows of corn grains fit closely together at the crowns, there may be considerable rot of the inner two-thirds of the grain with practically no fungus showing from the exterior. Sometimes a close inspection will reveal the white mycelium deep down between the rows, where a hasty inspection would fail to show it. When dry, such ears usually are rather loose and light in weight.

The characteristics that distinguish Diplodia ear rot from the other ear rots are: (1) a white, dense mycelium; (2) a dull brown color in the rotted kernels; and (3) the infection is not scattered but progresses thru the ear from either the tip or butt and may or may not involve the whole ear. Diplodia might be confused with Basisporium ear rot, which also has a white mycelium, but the mycelium of Basisporium is much looser, being more of a cobwebby nature while Diplodia is cottony. Furthermore the Basisporium mycelium is relatively inconspicuous, often being scarcely visible. The Basisporium spores, frequently present on the butt or on the kernels (Figs. 12, 16, 31), further distinguish Basisporium infections from Diplodia.

For *cause, seasonal cycle,* and *control* see pages 51 to 55.

GIBBERELLA EAR ROT

Importance. Gibberella ear rot is ordinarily of little importance. In some seasons the disease can scarcely be found. A loss of a little more than 1 percent occurred in 1926, but for the five-year average (1924-1928) it was less than one-half of 1 percent. Apparently the disease is dependent for its development on environmental conditions, and furthermore there are wide yearly variations in the amount of inoculum present. In some seasons Gibberella perithecia (Fig. 47) are abundant on old cornstalks, while in other seasons they can scarcely be found.

Symptoms. Gibberella rotted ears are illustrated in Plate II, ears *C* and *D*. The reddish coloration shown there is very characteristic. The fungus mycelium varies in color from white to pink. The rotted kernels themselves take on a bright red color. The rot practically always begins at the tip end of the ear and only very seldom progresses thru the whole ear. The ears illustrated in the colored plate show the typical condition. Only a few totally rotted ears have been found by the writers, and only a small number with rot beginning at the base. Spores seldom have been found on the infected ears, altho they can be obtained by culturing the fungus on a suitable medium. This is the Fusarium No. 2 of Burrill and Barrett.[5*] Gibberella ear rot will not usually be confused with Diplodia rot, being distinguished by its reddish color, and it should not ordinarily be confused with Fusarium ear rot, for Gibberella rot progresses rather uniformly down the ear while Fusarium rot is more irregular. The Fusarium fungus produces microconidia abundantly, and this serves as a good means of identification when a compound microscope is available.

For *cause, seasonal cycle of parasite,* and *control* see pages 58 to 60.

FUSARIUM EAR ROT

(*Fusarium moniliforme*)

Importance. Fusarium ear rot causes considerable loss, which at times is greater than that from Diplodia ear rot. As a six-year average (1924-1929) it was found to cause a loss of slightly more than 2 percent of the crop. Yearly losses were as follows: 1924, 1.0; 1925, 2.7; 1926, 2.9; 1927, 2.3; 1928, 3.0; 1929, 1.6 percent. Prior to this time, in 1921, when ear worms were abundant, losses of over 25 percent occurred in many fields in the state. Fusarium is very prone to follow injury made by the ear worm, but in addition, a certain amount of Fusarium ear rot can be found in practically every cornfield in every season in the absence of ear worm injury, and usually the loss is of importance. In the horny, utility type of corn the rot usually does not involve a large percentage of the kernels on an ear, so that the ear still has considerable feeding value, but in the late-maturing, "starchy" types the rots often are so extensive that the ears are worthless. Such rots are especially destructive in years when seasonal conditions are unfavorable for the maturing of the ears.

Symptoms. Usually Fusarium rot is scattered on the ear, as shown in Plate II, ears *A* and *B*, and Fig. 55, ears *B* and *C*. Sometimes the rot occurs only at the tip end of the ear, as on ear *A* in the same figure. Seldom does an ear become totally rotten, but the majority of the kernels are frequently involved. In the early-maturing horny types of corn this rot is rather dependent on previ-

FIG. 55.—FUSARIUM EAR ROT

In ear *A* the rotted tip probably followed injury by birds. In *B* the rot has become severe in a localized area and is due possibly to favorable moisture conditions in that part of the ear at the critical period. In a season favorable for the growth and maturity of corn, some kind of seed-coat injury usually occurs before Fusarium rot attacks the "utility" type of ear. In rough, floury (starchy) types the rots, when they occur, are usually much more extensive than here shown.

ous seed-coat injury to the kernel. Where only the tip end of the ear is involved in the rot, birds, worms, or other insects very likely have previously injured the kernels. When scattered infection occurs, as in ear *C*, Fig. 55, the seed coats of the infected kernels had previously burst open at the crown as a result of physiologic processes within the growing kernels. The pressure within the kernels, as well as the strength of the seed coats to withstand this pressure, naturally varies with individual kernels, and therefore those that crack open naturally are scattered somewhat at random over the ear. From these points on the ear the rot frequently extends to the neighboring kernels, and thus sometimes a rather large contiguous area may be involved, as shown in Fig. 55, ear *B*.

When the rot occurs only on the tip end, the remaining kernels of the ear may or may not be infected (without showing rot), but when the rot is scattered, experiments have shown that practically all the apparently sound kernels carry the infection at the pointed end where they are attached to the cob. It is apparent, therefore, that such ears are infected thruout but that the rot occurs only in scattered places wherever the fungus can gain entrance to the interior of the kernel thru the broken seed coat. That the cracking precedes the rot and is not caused by it seems evident, for ears frequently are found that have cracked kernels without being infected. Such an ear is shown in Fig. 59, ear *A*. When the cracked kernels show no rot, none of the kernels of such ears have been found to be infected with *Fusarium moniliforme*.

The relation of ear worm injury to this Fusarium rot has already been mentioned.

In some corn types, especially in the later maturing and more "starchy" strains, considerable Fusarium ear rot may occur without previous seed-coat injury. Here too the rot is scattered or blotchy, but often involves large sections of the ear. It seems evident that in this case also the infection first spreads thruout the ear, actual rot beginning with the kernels that are most susceptible, and these would be expected to occur at random over the ear.

The mycelium and spores of *Fusarium moniliforme* are a pale salmon color, and there is some tendency for the rotted kernels to take on a reddish tinge, and at times this reddish color is pronounced. Spores develop abundantly on the rotted areas. This is the Fusarium No. 3 of Burrill and Barrett and apparently also their Fusarium No. 1, altho there is a discrepancy in color. They describe the fungus growth as white, and indeed it does appear almost white at times. Ear *B* of Fig. 55 is such a case.

For *cause, seasonal cycle of parasite,* and *control* see pages 15 and 16.

BASISPORIUM EAR ROT

Importance. The importance of Basisporium ear rot varies considerably from year to year, more so than Diplodia ear rot, altho it does not vary so much as Gibberella ear rot. Many infected ears (Fig. 56) are nearly a total loss. The kernels become very light and chaffy and have practically no feeding value. In stages where the infection has not gone so far, some of the ears readily pass as marketable corn. For six years data on light, chaffy, unmarketable ears showing Basisporium infection have been obtained. These averaged slightly less than 1 percent of the crop by weight, but as these rotted ears are light in weight, the actual loss in yield was somewhat higher than this figure.

Symptoms. The cobs of badly infected ears break very easily, both crosswise and longitudinally (Fig. 57). This has suggested the name "cob rot,"[2*] and this name has been used to some extent but it is not used in this bulletin because the disease involves the whole ear—the kernels as well as the cob. Badly infected ears are always chaffy (Fig. 56) and light in weight and the shank attachments shredded (Fig. 11, third ear). But not all chaffy ears or those with shredded shanks are infected with Basisporium. The most easily observed definite symptom is the presence of the characteristic spores of the fungus showing at the butt of the ear or on the tips of the kernels, as illustrated in Figs. 12 and 16. Sometimes a certain amount of white, loose fungus mycelium occurs between the

FIG. 56.—BASISPORIUM EAR ROT

When infection with Basisporium takes place early, the ears may become badly rotted. Chaffiness also is characteristic of this disease.

rows, as shown in ear *A*, Fig. 56. The kernels become light and shrunken, but when the whole ear is viewed, the kernels usually show little evidence of rot. However, when the kernels are shelled

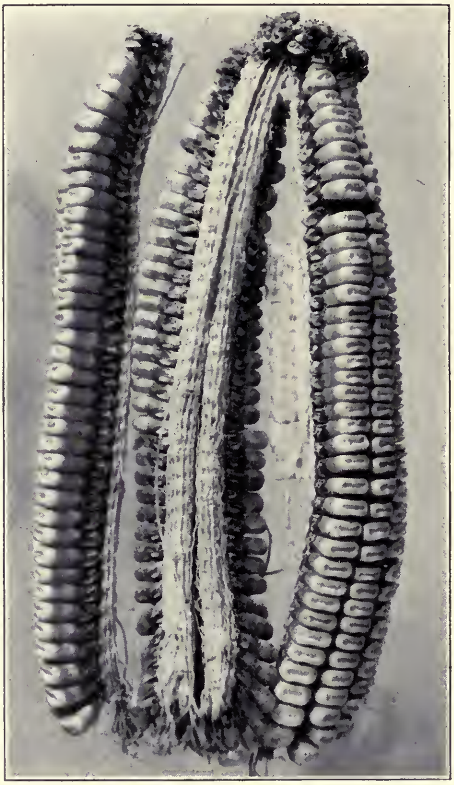


FIG. 57.—A ROTTING OF THE COB CAUSED BY BASISPORIUM

The cobs of ears rotted by Basisporium break very easily both crosswise and lengthwise. If the ear is very damp while the rot is progressing, the cob may actually fall to pieces, as here shown.

off, they are seen to be badly discolored, and on cutting them open it is evident that the interior, especially the germ, is badly rotted.

It seems doubtful if Basisporium is able to attack vigorously growing ears but, on the other hand, it has been demonstrated that when the shanks are killed, even as early as when the corn is in the milk stage, the ears may soon be entirely permeated with the fungus. Thus it appears that the disease is destructive principally after the ears have been killed or lowered in vigor prematurely by root, stalk, or shank rots or other diseases, or by cold when the ears are still high in moisture, or when very damp weather prevails after the ears have attained maturity.

For *cause, seasonal cycle of parasite,* and *control* see pages 65 to 67.

PENICILLIUM EAR ROT (BLUE MOLD)

In examining cornfields in various parts of Illinois, certain fields have been found in which a high percentage of the ears were infected at the tip end by a blue mold. The position and appearance of the mold is very much like that of ear *A*, Fig. 55, except that the mold is a dull blue and is covered with dusty blue spores that come off easily in large quantities. Probably a number of species of Penicillium are concerned in such rot. *Penicillium oxalicum* has been mentioned by Thom and LeFevre[109*] as occurring commonly on corn. The black and yellow molds (Aspergilli) have been reported as causing considerable ear rot in Texas at times[106*] but they appear to be of little or no consequence as an ear rot in the field in Illinois. These fungi are of considerable importance in the state, however, as the cause of storage rots (page 128).

CROWN CRACK OR POP

Cracking of the crowns is a common defect in dent corn. Very often the crack is inconspicuous, but at times the seed coat opens up and exposes the endosperm, giving a "popped" effect, as illustrated by ear *A*, Fig. 59. Apparently there is a time during the development of the ear when the seed coat is not able to stand the pressure within, and consequently breaks. In general, the cracked kernels are distributed at random over the ear. It seems reasonable to suppose that there may be differences in the strengths of the seed coats of individual kernels even tho it is all maternal tissue, and the hydrostatic pressures within kernels would also very likely vary at random. This would cause the cracked kernels to be distributed miscellaneously over the ear.

Corn ears recovered from the graves of ancient cliff dwellers have shown this same cracked or popped condition.[10*] Zapparoli[119*] described this type of injury and called it "broken seeds in maize."

He showed that the tendency toward this condition may be inherited. The name he gave does not distinguish this condition from the "silk cut" described next. Altho some of the kernels suggest a "popped" effect, the majority of the affected kernels show only a crack (Fig. 55, ear *C*). The condition is therefore here called "crown crack."

The injury is very often followed by infection with *Fusarium moniliforme,* which results in a more or less serious ear rot. Even tho free of infection, the kernels should not be used for seed purposes.

SILK CUT

Sometimes kernels of corn become cracked, as shown in Figs. 58 and 17. The break usually begins about half way up on the

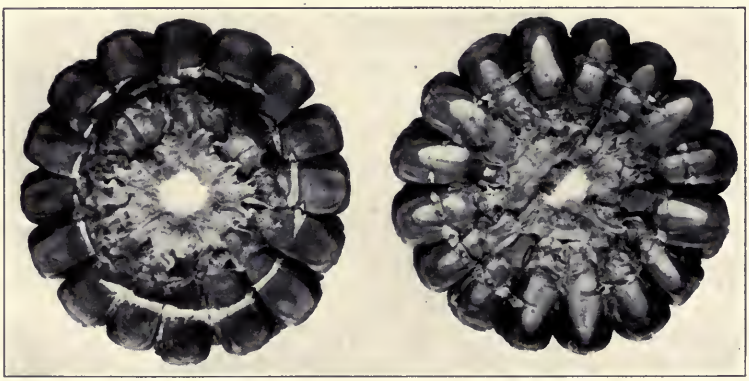


FIG. 58.—SO-CALLED "SILK CUT"

Note the transverse breaking of the seed coat on the germ side as well as on the back of the kernels. See also Fig. 17.

narrow sides of the kernel. Rather often it is not noticed that an ear has this injury until the kernels are shelled. Usually only a portion of the kernels of an ear are affected in this way. At times the cracking involves the germ. As a sound seed coat is of value in seed corn, such ears should not be used for seed. The exact cause for this condition has not yet been determined. The name here used seems to be in general use by the grain trade.

DEFECTIVE ENDOSPERM

Sometimes kernels with defective endosperms are found in open-pollinated corn. An ear having such kernels is shown in Fig. 59, ear *B*. In the inbreeding process to obtain pure lines, such defects are often found. This is not a disease, but the condition is described here because one not familiar with it might easily take it for a diseased condition. The seed coat grows to nearly full size,

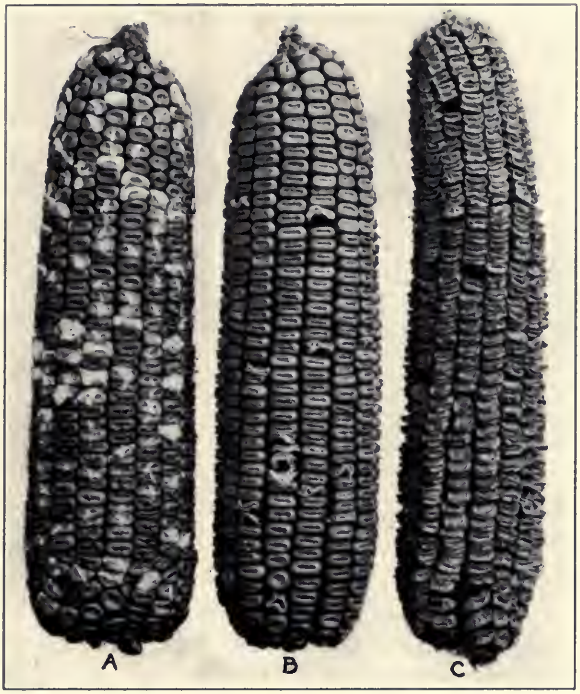


FIG. 59.—THREE DEFECTS: CROWN CRACK OR POP, DEFECTIVE ENDOSPERM, AND CHAFFINESS

Crown crack (*A*) occurs when the seed coat is too weak to withstand the hydrostatic pressure within the kernel during the growing period. Defective endosperm (*B*) is an inherited condition, while chaffiness (*C*) may be the result of a variety of causes, as explained in the text. All such conditions should be guarded against when selecting seed.

but the endosperm fails to develop properly. As a result, the defective kernels are flat and whitish because the color in yellow corn is not in the seed coat but in the endosperm. Mangelsdorf[76*] says, "There are many types of defective endosperm in maize ranging from those which exhibit only a transparent, empty pericarp to those in which development is slightly less than normal. These varying degrees of defectiveness are not the diverse expression of the same hereditary character, but each is inherited as an independent unit."

The condition is definitely inherited. The flat kernels failed to inherit the factors that are responsible for normal endosperm development. As observed under natural field conditions, when defective kernels are found they always occur scattered among normal kernels on an ear.

CHAFFY EARS

Chaffy ears are those on which all the kernels are imperfectly developed, so that the kernels are not tightly compressed against each other. Such ears are light and usually they are not solid but can be bent to some extent (Fig. 59, ear *C*). This may be the direct result of disease. Often the condition is due to Basisporium ear infection, which has already been discussed. Then too it may be caused by disease in other parts of the plant which cuts off the food supply from the ear. This is especially true in the case of shank or stalk infection with Diplodia or some other organism as a result of which the shank or stalk breaks early or ceases to function properly. Root rot may possibly also bring it about by causing the plant to die prematurely.

A considerable number of other causes may also be responsible for this condition. Among these might be mentioned: hail injury; cold injury; unbalanced soil fertility, especially a potash deficiency; insect damage such as that done by chinch bugs or corn root worms. In short, anything that arrests the development of the ear so that it dries before having attained maturity is likely to cause chaffiness.

FAILURE OF FERTILIZATION

Two types of failures in fertilization may occur. These are both illustrated in Fig. 60. Neither one is directly due to disease. It should be borne in mind that every kernel on an ear has resulted from a fertilized flower. Each flower has a long style, commonly called silk, which extends along the cob and out between the tip ends of the husks, where it is exposed to the air ready to receive pollen. After a pollen grain falls on a silk, the pollen grain germinates and a strand from this pollen grain grows all the way down the silk, enters the ovary of the flower, and fertilization takes place under normal conditions. About 24 to 36 hours are required from the time of pollination until fertilization is completed. This process must take place for each individual kernel. The flowers at the butt end of the ear are the first to develop and put out their silks, while those from the tip end come out a few days to a week later.

In the case of ear *A* in Fig. 60 the flowers were normal but the ear probably did not arrive at the silking stage until a little late in the season. The first silks to come out received pollen, the flowers were fertilized, and normal kernels developed. But after the ear was half pollinated, the pollen supply was suddenly cut off, owing no doubt to a change in the weather conditions. When weather conditions were favorable again there was no more pollen, the pollinating season being over. This left the tip half of the ear unfertilized, and thus no kernels developed. In the case of ear *B* in the same figure, the situation was different. There apparently was no lack of pollen, for normal kernels are scattered from butt to tip, and the plant was not isolated but grew in a cornfield. It is probable that many of the flowers were nonfunctional, or else possibly some unknown factor interfered with pollination, but if so, it is evident that the factor was operative thruout the silking period of the ear.

FIG. 60.—RESULTS OF PARTIAL FAILURE OF FERTILIZATION

Such conditions ordinarily are not caused directly by disease but by lack of pollen, as in ear *A*, or possibly infertility, as in ear *B*.

MECHANICAL INJURY

Injury to the seed coat may occur from rough handling, machine shelling, machine planters, chewing by mice and ear worms (Fig. 61), and other causes. It has been demonstrated at various times with small grains that seeds with cracked seed coats are inferior for seed purposes as compared with seeds with sound seed coats. The same has been found in corn.[1, 4*] The amount of loss in yield that might be expected from the use of such seed would no doubt depend considerably on environmental conditions. Under some conditions it might be negligible, and then again it might cause important reductions. Ears with considerable ear worm injury probably never find their way into the seed lot. On the other hand, after one has hung the seed corn up to dry, mice are apt to chew the soft starch off the crowns of the kernels. If the ears are properly dried and stored, such injured kernels will germinate, but they are greatly exposed to infection from organisms in the soil, when planted, and therefore such kernels should not be used for seed purposes.

FIG. 61.—INJURY CAUSED BY MICE OR EAR WORMS

Kernels with broken or damaged seed coats should not be used for seed. There is nothing to prevent disease organisms from entering such kernels after they are planted; thus the vigor of the seedlings is reduced and yield lowered.

STORAGE ROTS

The Aspergillus and Penicillium molds are among the most important rot-producing fungi in the crib when the moisture content of the corn is below 22 percent. When the moisture percentage is higher, other fungi predominate. Studies have been made on the fungus flora in corn meal at various moistures.[108, 109*] It was found that some of the *Aspergillus glaucus* group made some growth at a moisture content as low as 13 percent. Those of the *A. flavus* group appeared at 16 percent moisture, and the *A. niger* group and numerous other molds appeared at 19 to 20 percent. *Penicillium* spp. appeared somewhere above 16 percent. On account of the seed-coat protection of whole kernels, a higher moisture percentage than those indicated probably is necessary for initial infection to take place on ear corn. After infection has once started, however, molding possibly may occur in ear corn at moistures similar to those in corn meal. Kernels with injured seed coats would be the first to show deterioration.[1*] When sound shelled corn was stored under conditions where a uniform moisture of 15.5 percent was maintained in the grain, the senior author found that in one month's time at room temperature, species of Aspergillus became pronounced at the tip ends of the kernels and at breaks in the seed coat. At 14 percent moisture the corn remained apparently free of fungous growth.

Penicillium and Aspergillus attack the germ especially. This causes the germ to take on a blue color. When the pericarp is removed from such germs, a dense mass of blue or greenish fungus spores are exposed. In the trade this condition is called "blue eye" and is discriminated against. It has been found that this condition greatly reduces the oil content of the grains.[86*]

It has already been mentioned that *Diplodia zeae* is active under storage conditions at a moisture content of 22 percent or over. The moisture relations for *Fusarium moniliforme, Gibberella saubinetii,* and *Basisporium gallarum* have not been determined. Durrell[22*] believes that Basisporium is of slight importance in storage.

Time and temperature are important factors in addition to moisture in the development of storage rots. The lower the moisture, the longer the time necessary for rots to take place. Similarly the lower the temperature, the slower the development of rot, and at freezing temperature the fungus growth stops altogether. Very little corn is dry enough at the time it is cribbed to prevent the development of rot, but it is usually dry enough and cool enough so that the fungus growth is slow. As the autumn or winter advances, the corn ordinarily continues to become drier and the temperature becomes cooler so that the growth stops before much, if any, damage is done.

DAMAGE FROM FEEDING ROTTEN CORN

Serious diseases have developed in animals at various times when they were fed on rotten or moldy corn. In each case recovery from the disease began to take place when sound corn was fed in place of the infected material, and the disease again became acute when feeding of the infected corn was resumed.

Some years ago it was reported that a certain type of poisoning of animals occurred when they were fed on corn badly infected with *Fusarium moniliforme.*[82*] The disease resembled ergotism. Horses, cattle, and hogs became thin, some of the hair dropped off, and finally the hoofs sloughed off. Many of these animals died. The chickens lost their feathers and the eggs were invariably infertile.

More recently a disease of cattle caused by feeding on Diplodia rotted ears was reported.[81*] When cattle were turned into the cornfields in the winter months after the meadows failed, they began to suffer from a certain type of paralysis. Other animals were not so affected. Many of the corn ears were on the ground at this time and there was a high percentage of Diplodia rot. By collecting these infected ears and feeding them to cattle kept in the barn, the same symptoms developed. Furthermore, when sterile corn was inoculated with *Diplodia zeae* and later used for feed, the disease speedily became evident.

Moldy corn infected with *Aspergillus* spp. and other molds when used for feeding horses has been found to cause the disease called blind staggers.[33*]

An experiment has recently been conducted by Graham and Tunnicliff at the University of Illinois[30*] in which female hogs showed marked clinical symptoms (vulvovaginitis) when fed on moldy corn. A blue mold (Penicillium or Aspergillus or both) predominated on this corn, but certain amounts of other molds and ear rot fungi, especially *Fusarium moniliforme,* also were present.

It is the opinion of Thom and Church[108*] that altho moldy food often is harmful to humans and beasts, the fungi on this moldy food seldom are the direct cause of the harmful effects. In most of the experiments just mentioned, refined methods to determine the exact cause of the toxicity have been lacking. Only relatively few fungi are now known to be toxic. Thom and Church point out that while the molds usually are conspicuous on spoiled foods, many bacteria, entirely invisible, follow the molds in the spoilage process. They suspect that certain kinds of harmful bacteria usually are associated with the fungi when spoiled food becomes toxic to animals. *B. botulinus* is mentioned as one of these bacteria. For this reason moldy food should always be regarded with suspicion as it may contain harmful bacteria, tho in the majority of cases such bacteria probably are absent.

The explanation just made fits the situation very well, for many farmers are feeding moldy corn with apparently no harmful results, while in other cases there is no question but that the moldy food has caused disease and death of various animals. Further research on this subject is needed.

In the winter of 1930 several samples of immature, dry, shelled corn which hogs had refused to eat were received by the senior writer. The corn was not moldy in appearance. When surface-sterilized and plated, practically all kernels produced fungous growth. Several kinds of fungi were in evidence. No attempt was made to determine the cause of the unpalatableness to hogs. It is well known that hogs will refuse barley badly infected with Gibberella, but no Gibberella was noticed on these kernels of corn. It has been reported[a] that an extract from Gibberella infected corn ears will produce vomiting and sickness in hogs.

FUNGI AND DISEASE SYMPTOMS ON THE GERMINATOR

PLACE OF GERMINATION TEST IN CORN IMPROVEMENT

There seems to be no doubt that for very best results, a germination test for viability, vigor, and disease symptoms should be made of every ear of corn to be planted, and under certain seasonal conditions such a test is imperative. By separating out those ears that show *sturdy plumules,* a *vigorous root system,* and *freedom from disease symptoms,* as contrasted with those that show dead seed, poor vigor, or diseased conditions, distinct gains in the yields of planted corn are made.

The germination test, however, does not take the place of certain other measures, not even seed treatment, and on account of the greater difficulty in making it, primary emphasis in farm practice should be placed on strain selection, plant selection, ear selection, and seed treatment. It is a waste of time to test ears or pay to have them tested when close inspection of the ear and kernels would show the ear diseased or very apt to be susceptible to disease. Furthermore an ear may show good vigor and entire freedom from disease on the germinator and still the plants grown from it may prove susceptible to smut, root rot, or some other disease not

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[a]Oral report by J. G. Dickson before the annual meeting of the American Phytopathological Society at Ames, Iowa, December 30, 1929.

carried on the seed. Examination of the parent plant in the field will often disclose such susceptibility, altho there is always the possibility that a plant may be free from the disease simply because it has escaped infection and not because it is resistant to the disease. It is when the germination test is used to supplement rigorous physical selection of plant and ear (pages 28 and 32) that it has a valuable place in corn improvement, tho even under these circumstances it holds a less important place than formerly owing to the development of good seed treatments (page 37) which partially prevent the damages otherwise done by seedling diseases.

The fact that differences in ears selected on the basis of the germination test are relative, not absolute, must also be taken into consideration. A good germinator constructed on correct principles and operated by a competent person is the first requirement for a reliable test, but the best operator is subject to many variations in judgment, and even slight variations in the conditions of the test—in moisture, for instance—may mean that certain disease symptoms will fail to develop sufficiently to be noticed. Finally kernels from the same ear may vary in their susceptibility to or infection with disease.

Thus when using the germination test, its limitations must be recognized.

OPERATING THE GERMINATOR

It is not within the province of this bulletin to go into details about the construction of a germinator, but some remarks about its operation would seem to be necessary since many germinators now in use are not properly handled and good readings on disease symptoms consequently are impossible.

Two types of tray germinators are in use in this state, the cabinet type[73*] and the room type.[46*] Each includes a series of trays placed one above the other, each tray being provided with a wire bottom and a three-fourths inch layer of a limestone-sawdust mixture. The heat for either type is best applied at the bottom. Steam or electric heat is satisfactory. A water pan the size of a tray is placed over the heating elements and beneath the lowest tray. This keeps the lowest tray from drying out, and by placing the pan the proper distance from the heat enough evaporation is obtained to keep the relative humidity of the air up to 100 percent. This is very desirable, for direct application of water to the trays after the corn has begun to germinate should be avoided if the most satisfactory readings are to be obtained.

Moisture Supply. Maintaining the correct moisture relation in the germinator is one of the most difficult problems. The relative humidity of the atmosphere can easily be determined by means of a wet and dry bulb thermometer (hygrometer), and it is not difficult to keep the relative humidity up very nearly to 100 percent. What is more difficult, however, is to provide the correct supply of liquid water for the germinating kernels, neither too little nor too much. If the supply is inadequate, germination is slow and irregular; if it is abundant, the kernels will germinate very well, but some of the disease symptoms will be suppressed, especially those of scutellum rot. As there is no practical way of accurately measuring the water available to the kernels, as for instance measuring the thickness of the water film surrounding each kernel, the water relation must be adjusted by judgment, and thus there is much opportunity for error.

No more water than is necessary for germination to proceed promptly and evenly should be applied. When the white streaks show plainly on Cephalosporium infected kernels (Plate V, *G-H*), moisture conditions are about right. If there is too much water, these streaks will not show. As this disease occurs in greater or less degree on practically every lot of commercial seed, it can be used as something of an indicator for moisture conditions.

Temperature. Any temperature from 70° to 85° F. probably is satisfactory for the germination test, but the test is completed in the shortest time at the upper temperature. The important consideration in respect to temperature is that the temperature wanted, once having been determined, should be kept nearly constant. This is required, not because a fluctuating temperature within certain limits influences the test directly, but because it affects the moisture conditions. When the relative humidity of the air is 100 percent, a fall in temperature causes a precipitation of water. A rising temperature on the other hand causes a drop in the relative humidity.

Aeration. Change of air in the germinator is necessary for a satisfactory test. Usually there is little trouble in this respect with the room type of germinator. The necessary opening and closing of the door several or many times a day usually supplies adequate ventilation. Large germinators often have additional mechanism.

In the cabinet type of germinator that the writer has had occasion to observe, ventilation in some cases has been so inadequate that the tests were of very little value in detecting disease symptoms. Because the cabinets are small, they are apt to be overcrowded. If the kernels are laid out in rows 1 inch on center between kernels in the row and 2½ inches on center between rows, and a sufficient number of ventilating holes at the top and bottom of the cabinet are provided, there should be no trouble. Other methods of laying out the kernels may be used, but crowding must be avoided; otherwise aeration is apt to be inadequate, with the result that all the corn will be overrun by loose-spreading molds that hide the disease symptoms.

The rate of air exchange depends not only on the number and size of holes in the cabinet, but also on the difference between the inside and outside temperatures. While a certain amount of ventilation is necessary, an excess is undesirable, for the heating and humidifying equipment may not be of sufficient capacity to condition the new air rapidly enough for good results.

Sterilizing Cloths and Tray. The heavy unbleached muslins with which the limestone-sawdust is covered and on which the corn is placed should be boiled in water every time after being used. The actual treatment of the cloth with boiling water need be for only a minute, but when a number of cloths are put in at one time, the boiling may have to be continued for half an hour in order that water at boiling temperature may be sure to penetrate all thru the mass. It is important that the muslins be heavy enough so that the roots will not grow thru them. The roots can then be cleaned off thoroly before the cloths are boiled. Any cooked corn refuse left on the cloths makes a good medium for fungous growth and consequently is very undesirable. The same type muslins may be used for covering the corn, or they may be of lighter weight, and they should be sterilized in the same way.

At the end of the season it is advisable to soak the limestone-sawdust mixture with a solution of formaldehyde, 1 part formaldehyde to 100 parts water, leaving the germinator closed over night. After that the germinator should be opened and left open until it is dried out well.

IMPORTANCE OF SEEDLING VIGOR

Good seedling vigor on the germinator is just as important a consideration, and in some cases more important, than the question of whether or not diseases are present. Not only should seed corn be relatively free from disease, but it should also possess those inherent factors which give it the vitality to grow into strong, productive plants when proper conditions for growth are provided. This consideration has apparently been overlooked by some who have beeen selecting corn by means of a germination test.

The degree of seedling vigor is judged by the length and diameter of the plumules and number, length, and branching of the roots. The seedlings with the tallest or the thickest plumules do not necessarily produce the best plants, but the plumules should be well developed in both of those characteristics. It is very important that the root systems of corn seedlings should be extensive; standard corn-belt varieties should have preferably not less than six main roots. These main roots should be of good diameter and length and the first should have lateral branches by the time the germination readings are ordinarily made.

RECOGNIZING DISEASE SYMPTOMS

On well-selected dent corn, on a good germinator, a *conspicuous* mold on the kernel or seedling usually indicates one or the other of the diseased conditions described in the following pages. A great many other molds and bacteria are present but only occasionally do they become prominent to the naked eye. Corn that is immature or has been injured by cold temperature, either in the field or while curing, is especially susceptible to mold attacks on the germinator. Corn grown from such seed usually has proved to be especially susceptible to several diseases; and altho the viability of the seed on the germinator is perfect, the yield is unsatisfactory. Seed showing any pronounced growth of mold on the surface should not be selected for seed purposes if it is at all possible to obtain other seed.

So far as is now known, the following discussions cover the more important specific seed-borne diseases that may be recognized by means of a proper germination test, but the list should not be construed as final.

Rhizopus species

The principal causes of scutellum rot on the germinator are species of Rhizopus. When the seedling is infected with this fungus,

Fig. 62.—Scutellum Rot Symptoms on the Germinator

Each row of kernels represents an ear of corn. The first and third rows are free from mold. Considerable Rhizopus growth occurs in connection with the kernels of the other two rows. The scutellum of such kernels usually is in a rotted condition.

a loose, cobwebby mold often spreads out away from the kernel more than an inch (Fig. 62). Sometimes conspicuous white flecks occur in scattered places on the mycelium, while at other times no such flecks occur (Fig. 63). These flecks seem to be parasites on the

Rhizopus, for when single spore isolations from such a Rhizopus growth are made, the flecks do not occur in the cultures therefrom. Usually the tiny black sporangia in which the spores are borne (Fig. 64) can be seen with the naked eye, scattered on the Rhizopus growth. They can be seen best against the white plumule or roots. After the test has gone far enough, the sporangia usually are more or less abundant, especially when the white flecks do not occur. These white flecks apparently retard sporulation.

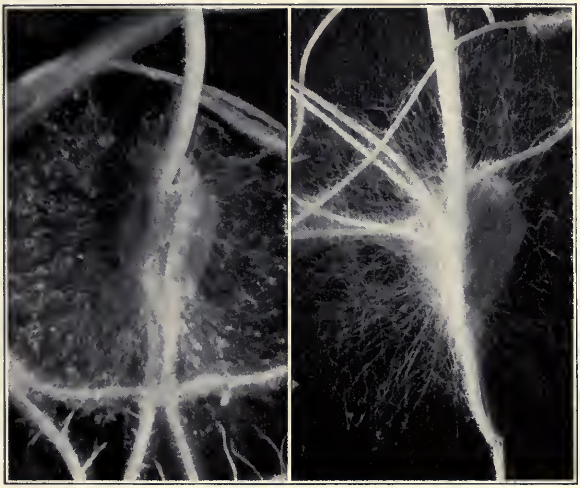


FIG. 63.—RHIZOPUS GROWING OUT OF SCUTELLUM-ROTTED CORN KERNELS ON A GERMINATOR

This fungus is the most common cause of scutellum rot on the germinator. The two types of growth illustrated are commonly seen.

When Rhizopus attacks the scutellum, the epithelium usually is first invaded and in a few days thereafter turns brown (Fig. 65 and Plate III, *G-H*). As the disease advances, all the scutellum may turn brown (Fig. 65, *C*), and the fungus may progress to some extent into the radicle and plumule (Fig. 65, *D*). Sometimes the rot begins at the bases of the lateral roots (Fig. 54, *E*), but this condition is not so common on the germinator as it is under field conditions.

It should be borne in mind that this disease does not develop as quickly on the germinator as do some of the others, and readings therefore should not be made too soon. It takes some time for the fungus to become conspicuous on the exterior of the kernel, for infection cannot take place until the seed coat has been ruptured in the germination process. Similarly the brown color of the scutellum tissues, characteristic of this disease, does not develop until the

FIG. 64.—RHIZOPUS SPORANGIA ON SCUTELLUM ROTTED, GERMINATING CORN KERNELS (Somewhat enlarged)

These sporangia occur in a scattered manner on the fungus growth if the germinator is aerated sufficiently, the test has gone far enough, and other conditions are favorable. They can be seen with the naked eye, especially against the white parts of the plumule and roots, but they do not always occur so abundantly as here shown. They help to identify the fungus. Each sporangium contains many spores.

germination is well advanced. In a well-aerated germinator satisfactory readings can be made when the plumules are about 5 inches tall. By this time the fungus usually has reached the sporulating stage. Dead kernels do not show scutellum rot.

This fungus does not develop well when there is an excess of water around the kernel (page 133). If conditions on the germinator are to be made favorable for Rhizopus growth, so that the susceptible ears can be detected and eliminated, the amount of water must be carefully adjusted. (For further discussion of this disease, see page 67).

To what extent ears should be discarded from the seed lot when Rhizopus growth occurs on the kernels in the germinator is difficult to say. A number of factors are concerned, but the most important are the amount of scutellum rot that is taking place and its effect

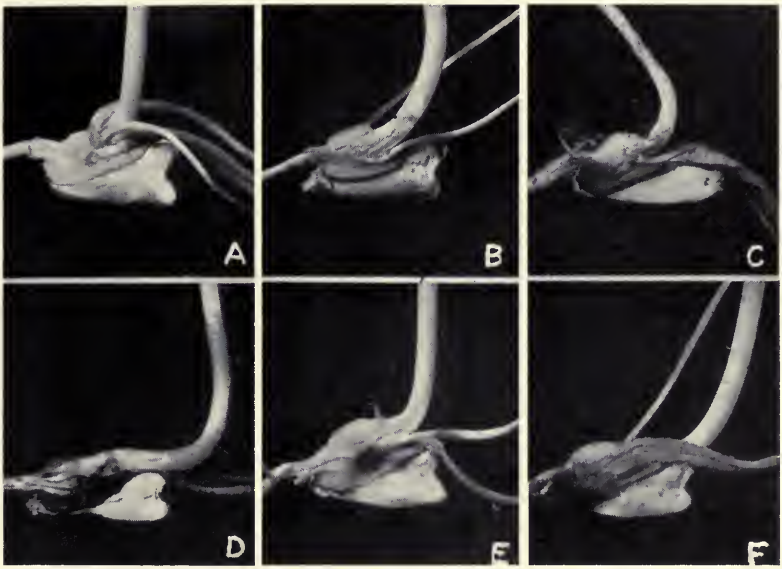


FIG. 65.—BISECTED KERNELS OF GERMINATED CORN SHOWING SYMPTOMS OF SCUTELLUM ROT

(*A*) healthy seedling; (*B*) epithelial rot of the scutellum; (*C*) more advanced stage, in which the rot has progressed to the cortical and vascular tissues; (*D*) still further advanced stage involving the whole scutellum; (*E*) a rot at the base of the lateral roots; (*F*) a rot of the base of the scutellum.

on the vigor of the seedlings. When scutellum rot is bad, the vigor of the germinating kernels is always checked, tho this may not happen until near the time when the readings are made. It has already been pointed out that this fungus cannot do damage so rapidly as internally borne parasites. Often the check in vigor is evidenced by spindly sprouts, and it is not unusual to see an actual wrinkling of the surface of the sprout, which shows that the plumule has been shrinking in its diameter. The amount of rot can be determined accurately only by bisecting and examining every kernel when the readings are made. If the germinator is a

PLATE III

A, B Vigorous disease-free seedlings.

Note the clean, healthy appearance of both exterior and interior, as well as the large number of strong roots. *The germination test is a valuable means of selecting seed with superior vigor.*

C, D Fusarium infected seedlings.

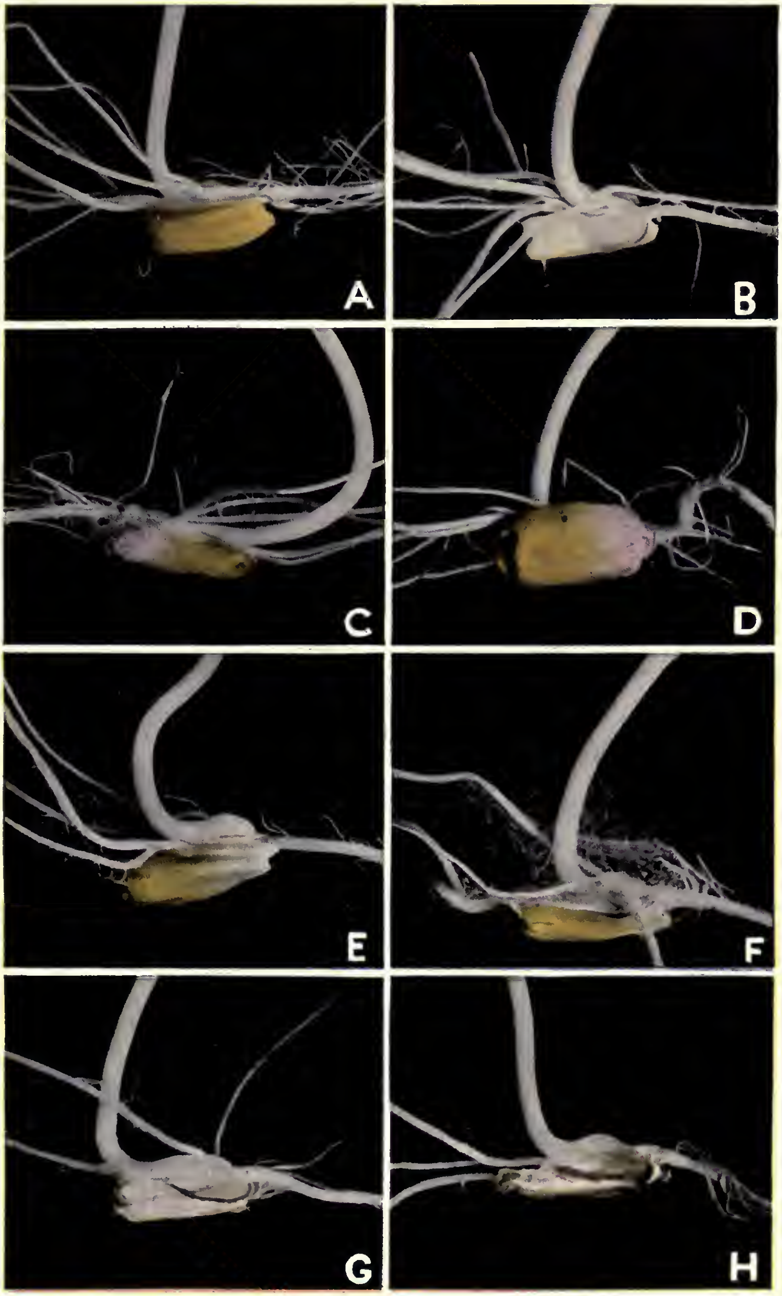
The pink fungous growth on the exterior of the kernels often is an indication of Fusarium infection altho at times Fusarium and Cephalosporium infections closely resemble each other superficially on the germinated kernel.

E, F Scutellum rotted seedlings, exterior appearance.

One seedling shows considerable Rhizopus mold, which is usually, but not always, evident on the kernels of such seedlings.

G, H Scutellum rotted seedlings bisected.

Note the brown rot of the scutellum, which is the portion of the embryo next to the endosperm.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good one, is properly managed, and the trays are not overcrowded with corn, after some experience at bisecting kernels, fairly accurate readings can be made by observing the amount of Rhizopus growth on the exterior. The closeness of the reading that is necessary depends considerably on the purpose for which the seed is to be used, tho ears that show evidence of being very susceptible to this disease should in every case be thrown out.

Scutellum rot is not of much consequence in carefully selected utility type corn compared with what it is in corn that has not been carefully selected toward resistance to this disease, that is, toward a well-developed, fully matured, horny, lustrous kernel (Table 3 on page 61).

Fusarium moniliforme

By careful and intelligent seed selection in a good strain of corn, a high degree of resistance to Rhizopus infection can be obtained

FIG. 66.—GERMINATED CORN KERNELS INFECTED WITH CEPHALOSPORIUM AND FUSARIUM

Cephalosporium acremonium (*A*) is a very delicate, downy fungus which often causes white streaks on the seed coat. *Fusarium moniliforme* (*B*) frequently presents a granular appearance, as here shown, but there are times when the difference between the two fungi is much less distinct than this to the naked eye. The fungous growth on the kernels is not always so extensive as here shown.

after several years' work; but such selection is not so effective against Fusarium infection, so that in such corn this remains the most extensive seed-borne disease.

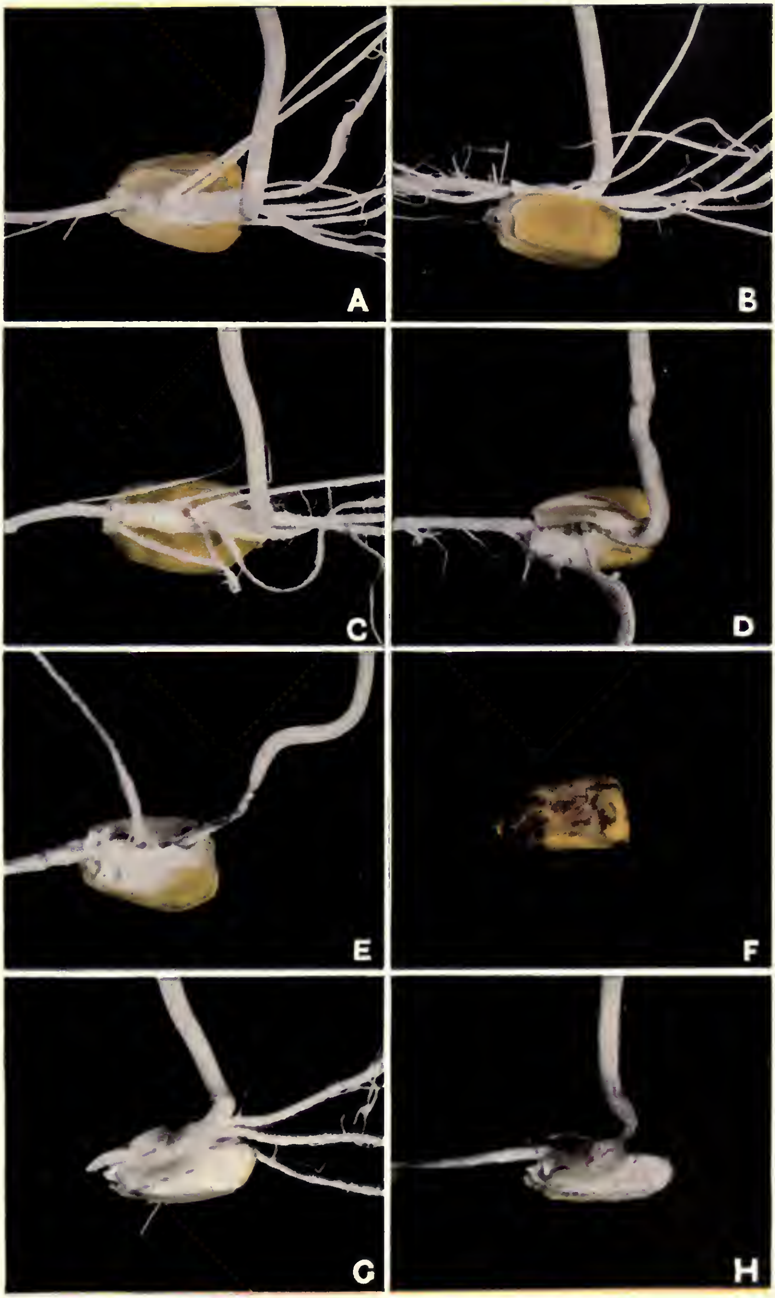
When the germination test has gone far enough, this fungus develops as a light pink growth close to the kernel, beginning at the

PLATE IV

A, B Vigorous, disease-free seedlings.

C, H Diplodia infected seedlings and kernel (*F*).

Diplodia zeae develops abundantly on infected kernels in a germination test and causes the decay of plumule and roots in the region near the kernel. In advanced stages the fungus itself appears as a dense white mold covering part of the kernel.



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tip end and spreading back more or less over the seed coat (Fig. 66 and Plate III, *C-D*). The amount of growth may be only a small tuft at the tip end of the kernel, that is hardly noticeable, or it may extend back so as to cover most of the kernel. It does not spread out away from the kernel. Occasionally some reddening of the seed coat develops on infected kernels by the time the test is read. Usually no rotting of the seedling occurs on the germinator but occasionally the base of the radicle becomes decidedly rotted.

There are many different strains of this fungus, and these different strains vary in appearance, not only in culture in test tubes, but also on the corn kernels, and no doubt they differ in their virulence.[74*] Sometimes the fungus appears rather granular to the naked eye (Fig. 66, *B*). In such cases it is easily distinguished from *Cephalosporium acremonium*, but at times these two fungi appear so much alike that they cannot be distinguished without the aid of a microscope. (See Cephalosporium, which is described next, for further comparisons of these two fungi.)

Altho Fusarium infected seedlings ordinarily show very little rot on the germinator, and the vigor of the seedlings is not reduced to any great extent, yet the use of infected seed causes consistent reduction in corn yields (Table 3). In the selection of first-class seed, ears showing infections of this kind should therefore be discarded. (For further descriptions of the disease see page 60.)

Cephalosporium acremonium

Cephalosporium acremonium causes a blackening of the vascular bundles of the older plants. It is one of the most difficult diseases to detect on the germinator. Often the fungous growth showing on the exterior of the kernel is so slight as to escape notice and is easily covered over by other molds. It is very small and delicate, very light pink in color and usually occurs only at the tip end of the kernel. (Fig. 66 and Plate V, *G-H*). When the liquid water on the germinator is kept down to the right amount, the seed coat at the tip of the kernel, next to the fungus, usually becomes white in color and white streaks often extend back over the kernels, as in the illustrations just mentioned. These streaks help considerably to identify infected seed, but they do not show when the trays are kept very wet.

Differentiation between Cephalosporium and Fusarium infections often cannot be detected without the use of a compound microscope. Fortunately, in a commercial test it is not ordinarily necessary to differentiate between them, for there is justification for

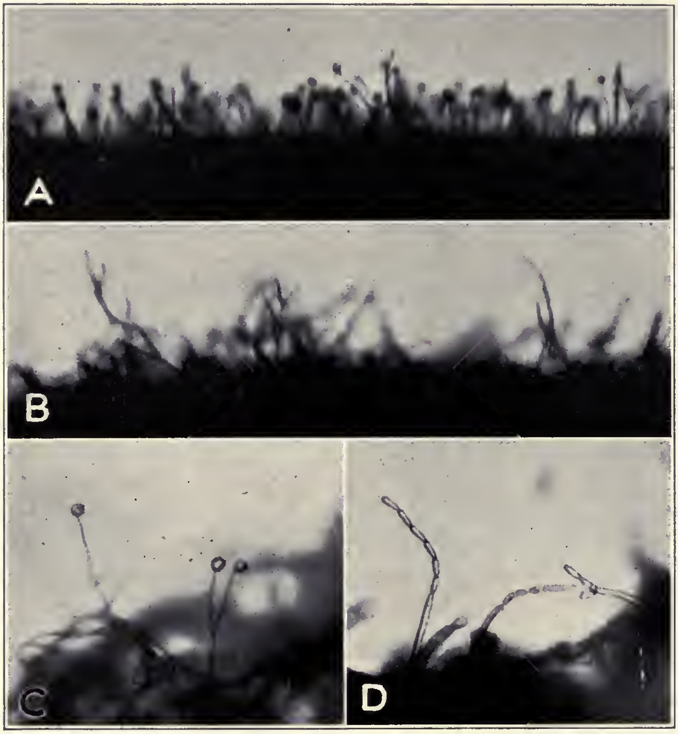


FIG. 67.—MICROSCOPIC VIEWS OF *Cephalosporium acremonium* AND *Fusarium moniliforme* ON GERMINATED CORN KERNELS

The spores of *C. acremonium* (*A, C*) are grouped into balls at the ends of stalks, while the spores of *F. moniliforme* (*B, D*) are arranged end to end in chains. This makes microscopic differentiation between these two fungi a simple matter. (*A, B* enlarged × 200; *C, D* enlarged × 350.)

discarding ears infected with either one. Many of the light infections, however, will escape notice, especially in a commercial test.

When it is desired to make a microscopic examination, it is best to turn the kernel with the back upward and then cut away the lower portion of the kernel, including the roots and sprout, taking care not to damage the tip end of the kernel. The kernel will then lie flat and steady, so that the 16-mm. objective of the microscope can be used without trouble. The mount is laid on a glass slide and is examined dry. Only that part of the fungous growth that projects around the outer edge of the kernel can be examined because the illumination is made from beneath. Fig. 67, *A-B*, shows how these two fungi appear in a dry mount with a 16-mm. objective, as just described. Spore balls occur at the ends of the stalks of Cephalosporium, as shown in *A*. These spore balls are characteristic of Cephalosporium and do not occur in Fusarium, which is shown in *B*. They are too small to be seen with a hand lens. If no spore balls such as are shown in *A* can be seen in a good mount, and if there is doubt whether it is *Fusarium moniliforme*, then a scraping should be made and placed in a water mount. As this Fusarium sporulates profusely, many of the small oval spores illustrated in Fig. 30 can be seen with the 16-mm. objective but still better with the 4-mm. These Fusarium spores are borne in chains (Fig. 67, *D*) but the chains are a little difficult to distinguish in a dry mount, and in a wet mount the chains break up so that the spores are seen singly, detached. Similarly the spore balls of Cephalosporium cannot be seen as such in a water mount, for then they break up into separate spores, which are very small (Fig. 30). (For a further description of the disease see page 78.)

Diplodia zeae

While seedling infection with Diplodia is not usually so prevalent as infections with the different fungi already discussed, yet wherever it does occur it usually is the most destructive of all the seedling diseases.

The fungus is seen as a dense white mold somewhat resembling cotton batting in texture. It seldom extends out more than half an inch away from the kernel or the infected part of the seedling. Whenever this mold occurs, it quickly causes a brown rot of the plumule or the roots, so that the seedling frequently is killed. Sometimes the seed is dead as a result of this infection. Such seed usually shows a dull brown to bluish-black color on the exterior when the germination readings are made. Infected seed and seedlings are illustrated in Plate IV, *C-F*. Sometimes the rot itself is the only conspicuous symptom, the white fungus not being visible on the exterior.

PLATE V

A, C Gibberella infected seedlings and kernel (*C*).

Gibberella saubinetii causes a brown decay of the seedling in the region near the kernel very much like that caused by Diplodia infection. Distinguishing characteristics are a yellow to pink color of the mycelium and more or less red coloration of the seed coat in the case of Gibberella.

D Aspergillus infected seedling.

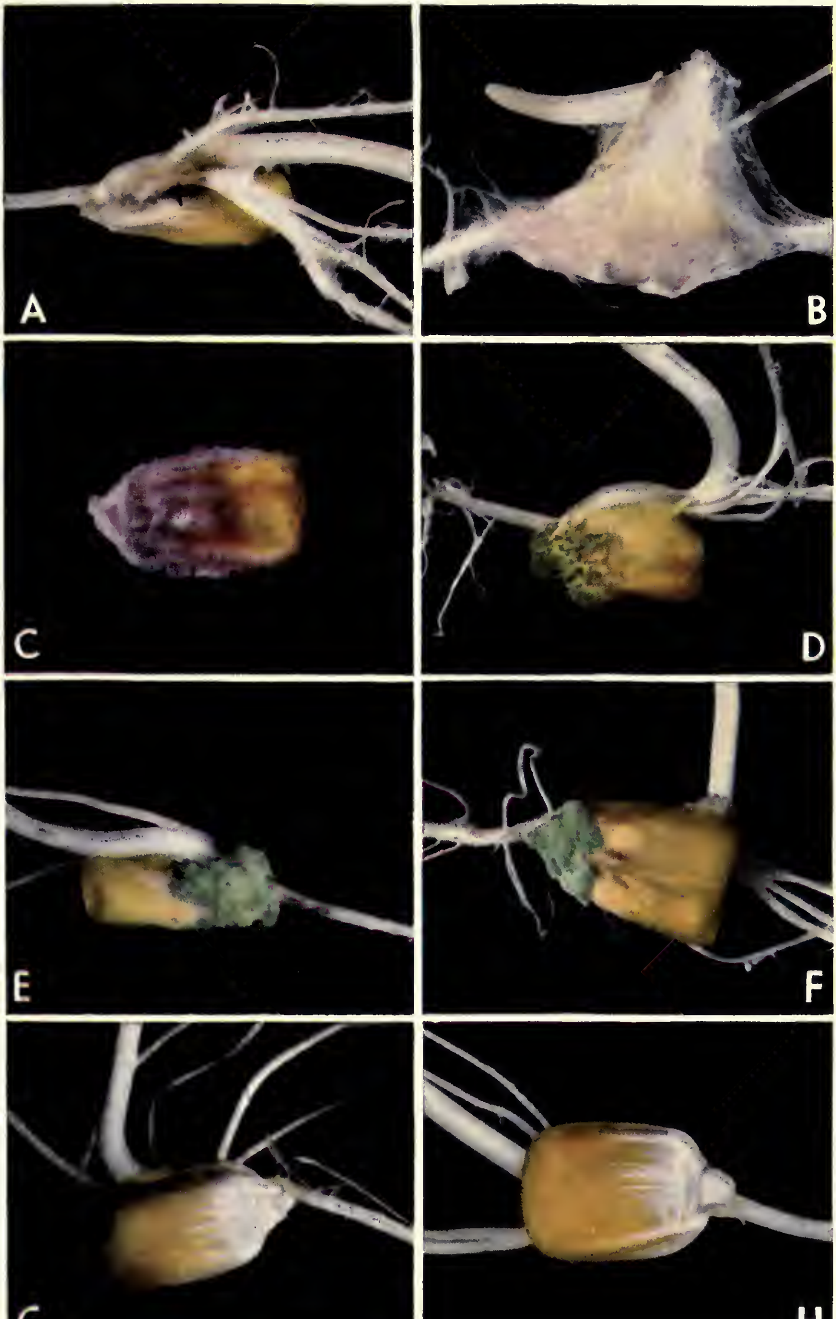
A number of Aspergillus species may occur on germinating corn kernels in a variety of colors among which are black, green, yellow, and brown.

E, F Penicillium infected seedlings.

Penicillium species occurring on corn usually are blue-green in color and frequently cause a rot of those parts of the seedling that are close to the fungous growth.

G, H Cephalosporium infected seedlings.

Cephalosporium acremonium appears as a light pink growth at the tip of the kernel. Under proper germinating conditions a bleaching and streaking spreads back over the seed coat from this point.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When there is no mold on the exterior, it is a little difficult to distinguish Diplodia rot from Gibberella rot. A comparison of the symptoms of the two diseases is given under Gibberella, which is described next. (For a further description of Diplodia seedling disease, see page 46.)

Gibberella saubinetii

Kernels infected with *Gibberella saubinetii* may be dead or the fungus may cause a rot of the seedlings somewhat like that described for Diplodia infection. Indeed there are occasional cases when the two diseases cannot be distinguished one from the other as they appear on the germinator. As a rule the Gibberella mold shows some yellow or pink color (Plate V, *B*), while the Diplodia fungus is white. Neither fungus is apt to sporulate during the period of the germination test, and furthermore the fungous growth does not always show on the exterior. In the case of Gibberella infection there usually is some red discoloration of the seed coat (Plate V, *A* and *C*), while Diplodia causes a dull brown discoloration. Sometimes it can also be noted that the Gibberella rot is darker brown and drier in appearance than the Diplodia rot.

Light Gibberella infections do not always become evident in the ordinary germination tests, and yet when such seed is planted at the proper corn planting time, when the soil is cold, considerable seedling injury may result. Fortunately a good seed treatment will largely prevent damage from these slight infections. (For a further description of the disease, see page 55.)

Penicillium species

Penicillium growths are very common on corn when the germination tests are read. Very often there is only an inconspicuous amount of fungus, and at other times the growth may be rather extensive (Plate V, *E-F*). It occurs at the tip end of the kernel unless the seed coat has been injured, when it may also occur thru the broken pericarp. It is of a loose, dusty nature (the dust is composed of spores), extending as much as an eighth of an inch out from the kernel and usually is blue-green in color. When a dry mount is viewed with a microscope prepared as explained under Cephalosporium, the fruiting stalks with their spore-bearing branches resemble tiny brooms or feather dusters with the feathers pointing away from the kernel (Fig. 1). These fruiting structures cannot be distinguished with the naked eye.

In some cases a rot can be seen at the base of the tap root of an infected kernel, and sometimes this rot may become rather extensive. It has been demonstrated that the fungus is not only surface-borne, but often occurs in the deeper tissues, where it is not reached by a surface disinfection process.

A considerable number of different species of Penicillium are found on corn, the majority of which are blue-green in color. Without a careful microscopic examination, many species appear practically alike. One of these, *Penicillium oxalicum,* is known to be decidedly harmful;[55*] some others have shown harmful tendencies but not to the same extent. Seed treatments are relatively ineffective against these fungi. When selecting first-class seed corn, therefore, the writers feel that ears should be discarded when the tested kernels show considerable infection of this kind. (For further description of the disease, see page 72.)

Aspergillus species

A characteristic of the Aspergilli that occur on corn is the usual occurrence of the spores in spherical clusters or heads at the ends of short stalks. Sometimes the color of the heads is black (Fig. 68), in some species they are green (Plate V, *D*), and yellow and brown species also are found. The heads can be clearly seen with the naked eye in many species, especially the black ones, but in some others they can only be differentiated with a hand lens.

In many respects the Aspergilli are similar to the Penicillia,

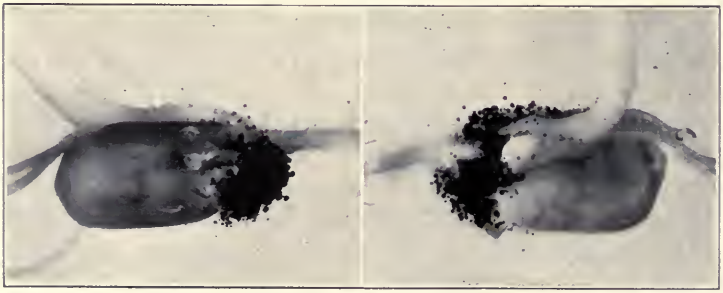

FIG. 68.—*Aspergillus niger* ON GERMINATING CORN KERNELS

Black spore heads, visible to the naked eye and each composed of many spores, are borne at the ends of stalks. They are nearly 100 times as large as those of Cephalosporium. Other species or groups of Aspergillus occur in green, yellow, and brown colors.

already discussed. As a rule they can be distinguished by the presence or absence of round spore heads, but there are many species within each genus and there are border-line cases which cannot be differentiated so readily. Both fungi begin growth at the tip end of the kernel unless the pericarp is broken, in which case they are apt to grow at the broken places also. A heavy growth of either of these fungi at the tip end of the kernel on the germinator is apt to cause a rot at the base of the scutellum (Fig. 65, *F*). When grown in soil, a rot of the mesocotyl and of the bases of the roots may occur.

An ear showing heavy infection with Aspergillus probably should not be included with first-class seed corn. (For further description of the disease see page 74.)

Basisporium gallarum

Many ears badly infected with Basisporium can and should be culled out before making a germination test. This is often overlooked.

Spores of Basisporium that were not present in the dry grain sometimes develop during the germination test. The black spores

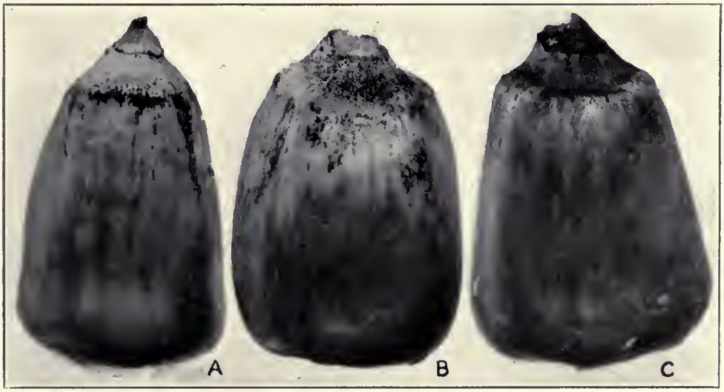

FIG. 69.—TWO BLACK MOLDS, *Basisporium gallarum* AND *Alternaria sp.*, ON GERMINATING CORN KERNELS

The black color of Basisporium (*A, B*) is due entirely to the black spores. These spores present a very granular appearance even to the naked eye. *Alternaria* (*C*) is downy in appearance whether viewed with the naked eye or with a hand lens. There are still other black molds that sometimes appear on germinating corn (see Fig. 70).

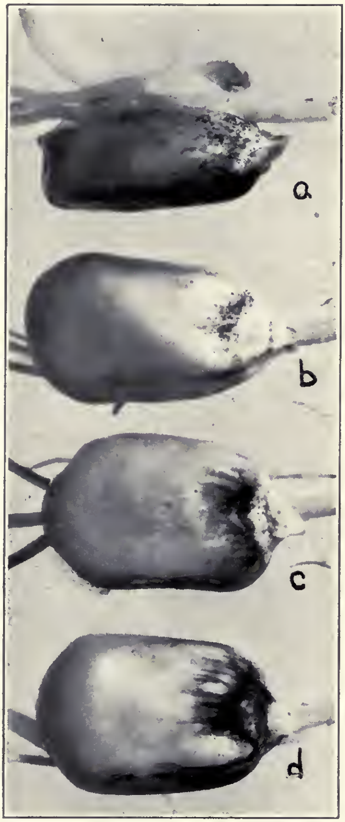

Fig. 70.—Basisporium and Hormodendrum on Germinating Kernels

Note granular appearance of basisporium spores on kernels *a* and *b*, and streaked, nongranular appearance of Hormodendrum on kernels *c* and *d*. Black streaks caused by Hormodendrum sometimes occur also on dry ungerminated kernels.

which serve as a means of identification appear on the germinated kernels (Figs. 69 and 70) very much as they do on the dry grain (Figs. 16 and 31). There is no conspicuous mycelial growth such as occurs in many other fungi on the germinating kernel. The spores are close to the kernel, not out on stalks like the Aspergilli. Altho the individual spores are too small to be seen with the naked eye, they occur more or less in small groups and these groups can be seen with the unaided eye as in the illustrations just mentioned. Nevertheless, these spores are large as compared with the spores of some fungi herein discussed, so that with a hand lens giving 10 magnifications the individual spores can be made out. Some Basisporium infected kernels, however, show no spore development at all, either on the dry or on the germinated kernel.

Not all black fungous growth or black discoloration indicates Basisporium infection. In some seasons Altenaria occurs at the tip ends of the kernels of some ears (see description below). With a good hand lens Alternaria will appear as a downy growth, while Basisporium shows the characteristic spores. While black streaks on the seed coat sometimes are associated with Basisporium infection, more usually they are caused by other fungi. Such kernels are shown in Fig. 70, *c, d*.

All ears showing Basisporium infection should be discarded. Laboratory studies have shown that in well-selected seed corn there may be at times a considerable amount of Basisporium infection which does not become evident in the germination test. Seed treatments seem to be the only hope for cutting down that type of infection. (For further description of the disease see page 63.)

Alternaria species

Alternaria appears as a slightly fuzzy growth, olive-black in color, more or less extensive at the tip end of the kernel (Fig. 69, *C*). A picture of the spores, as seen with the high power of a compound microscope, is shown in Fig. 30. They are dark in color. In a dry mount, made as explained under *Cephalosporium acremonium,* the spores can be seen joined end to end in chains. Infections of this kind were especially prevalent in the crop of 1928 in many parts of Illinois. This was coincident with a great amount of damage caused by low temperatures—not temperatures that necessarily injured the germination of the corn but temperatures that killed the plants when the ears were still immature and high in moisture.

Whether or not Alternaria tends to injure the seedling when infected corn is used for seed is not known, but it seems probable that corn on which such infection occurs will not prove of high quality for seed purposes.

Other organisms

Fungi other than those just discussed appear on germinating corn kernels, but on a well-regulated germinator they usually are not abundant. A number of bacteria also occur. A bright red bacterium is of special interest. It causes a red blotching of the seed coat and may cause a red spot on the muslin where the kernel rests. No rotting of any parts of the infected seedling have been observed, and as yet no pathogenic properties have been ascribed to this bacterium. People reading the germinator have sometimes confused this red bacterial coloration with Gibberella infection, which causes a red discoloration of the seed coat and sometimes a red spot on the muslin. *Fusarium moniliforme* also sometimes causes a red discoloration of the seed coat. Thus red discolorations may be caused by several organisms. When such discolorations occur in the absence of any fungous growth, rot, or reduction in vigor, there is as yet no evidence to show that such corn is unsuited for seed purposes.

Those not acquainted with the appearance of corn seedlings on the germinator sometimes mistake the root hairs (Fig. 71) for fungous growth. Sometimes roots are crowded with these hairs and then again they are relatively free from them, depending to some extent on the moisture conditions on the germinator.

FIG. 71.—GERMINATING DISEASE-FREE CORN KERNELS

The numerous exceedingly delicate root hairs which usually are abundant on the young roots have sometimes been mistaken for fungous growth by the uninformed.

SUMMARY

Occurrence of Corn Diseases

Corn, Illinois' most valuable grain crop, is subject to attack by many diseases. Losses to dent corn in the state as a whole, resulting from diseased conditions, have been conservatively estimated as more than 20 percent annually as an average. Surveys indicate probable losses from seedling diseases of about 9 percent; from black bundle disease, about 3 percent; from smut, about 3 percent; from root rots, about 5 percent; from stalk rots, about 2 percent, and from ear rots about 7 percent.

Corn diseases are caused by fungous infection, bacterial infection, virus infection, insect infection or poisoning, and by unfavorable environmental conditions. Fungi are the most common causes of disease.

Most of the diseases that have been observed in Illinois occur thruout the state. Two, bacterial stalk rot and brown spot, are found practically only in the southern half, and the black bundle and scutellum rot diseases are more pronounced in the southern region.

Of the nine seedling diseases discussed in this bulletin, scutellum rot, Diplodia, Basisporium, Fusarium, and Gibberella, are the most important. While each has its peculiarities, all are able to reduce the vigor of seedlings and sometimes to cause their death.

General diseases of the aerial parts of the corn plant are smut, black bundle disease, and bacterial wilt. Smut is a localized disease, infections occurring separately on the stalk, leaf, ear, or tassel. The black bundle disease is systemic, the infection occurring thruout the stalk, leaves, and ears. Both these diseases are most active on rich soil. Bacterial wilt, another systemic disease, is of special importance in sweet corn.

The exact causes of many of the root rots which are common in the state have not been determined. A Pythium organism has been identified as one cause, but it is not known to what extent it is responsible for root rot in general. In some cases an unbalanced condition of the nitrogen-potash ratio appears to make the roots unusually susceptible to rots by organisms that otherwise are active only on dead matter.

Stalk rots are caused by Diplodia and no doubt also by a number of other fungi. Sometimes unbalanced soil fertility is a contributing factor in stalk rots as well as in root rots. Cold injury to immature stalks induces susceptibility to rotting and also has undesirable effects on the ears.

Leaf diseases such as rust, purple sheath spot, and Helminthosporium leaf blight, while very common in the state, ordinarily cause little damage. A number of heritable defects—striped leaves, spotted leaves, "dying between the veins," and rolled leaves—are often confused with diseased conditions.

Of the five ear rots discussed four—Diplodia, Fusarium, Basisporium, and Gibberella—are of special importance during late summer and fall. Still other organisms cause spoilage of frosted corn. Storage rots are caused largely by species of Penicillium and Aspergillus.

Control

Damage from corn diseases can be greatly reduced by the carrying out of a general program of control measures, and these general control measures can be used by any interested farmer whether he is able to distinguish the various diseases or not. Practices important in such a program are:

1. Sanitation, that is, the removal of all old corn refuse from the field or the thoro plowing under of such refuse so as to remove it from the surface of the ground. Such refuse carries spores which otherwise are scattered by the wind and reinfect the next crop.

2. Crop rotation, in order to prevent the accumulation of disease organisms in the soil.

3. Soil management, including proper tillage, drainage, and soil fertility, in order to provide conditions favorable to the vigorous and balanced growth of the corn plant.

4. Development of disease-resistant strains in open-pollinated and inbred stock by careful plant and ear selection for freedom from disease, for characters found to be associated with resistance to disease, and for other desirable plant qualities.

5. Seed treatment, in order to check seed-borne diseases and protect the kernel or young seedling against infection from the soil, especially when the environmental conditions are unfavorable for germination.

In addition to the above control measures, the germination test for vigor and freedom from disease usually is of value. In seed lots that have poor viability, a germination test of the ear is very important. Special equipment and training are required, however, for a reliable test for disease, and with the development of modern seed treatments, the use of the test as a means of detecting disease symptoms is no longer so important as it once was. The value of seed treatment and the germination test, however, only partly overlap. Neither can entirely take the place of the other and each has advantages not covered by the other.

No one step in these general measures for controlling corn diseases is very effective without attention to all. It is only when a well-rounded program for corn improvement is followed out year after year that satisfactory results are obtained.

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GLOSSARY

(The definitions here given are restricted to their application in this bulletin.)

Antheridia Male reproductive organs in the lower plants such as fungi.

Ascomycetes That class of fungi which bears its spores in special sacs (asci), typically 8 spores to a sac.

Basidiomycetes A class of fungi in which, typically, four single spores are borne on 4 short pedicels at the end of a fruiting stalk.

Cauline roots Roots that arise from nodes on the stem (Fig. 20).

Chlorophyl The green coloring matter of plants which develops only in the presence of light, and which is necessary for photosynthesis.

Conidia, Conidiospores Spores produced at the ends of fungus stalks or branches (conidiophores) vegetatively, without sexual fertilization.

Crossbred Crossbred corn is produced by the transfer of pollen from one strain or variety to another. To some extent used synonymously with "hybrid."

Disease resistance See discussion page 22.

Disease susceptibility See discussion page 22.

Endosperm All the corn kernel except the embryo (germ) and the "seed coat."

Enzyme A substance produced by living organisms which digests food, usually changing substances so that they become soluble in water.

Epidermis The outer membrane or "skin" of the corn plant.

Epithelium A membrane, one or several cells in thickness, covering the surface or lining the cavities of some of the organs of plants as well as of animals. Epithelia have various functions such as absorbing nutrients, excreting wastes, and secreting enzymes.

Flora Plant growth of all kinds, including fungi and bacteria.

Fungus (fungi) See discussion page 6.

Genetic factor A term used to designate the determiner of a heritable character.

Genus A division in the classification of living things which includes closely related species.

Host Any live organism that is parasitized by another organism.

Immunity See discussion page 22.

Imperfecti A class of fungi in which sexual reproduction is unknown, but which in vegetative growth and asexual sporulation resemble the Ascomycetes.

Inbred Inbred corn is produced by self-pollination practiced during one or more successive generations. The longer this practice is continued, together with selection for the characters desired, the nearer the strain comes to being a "pure line" for those characters.

Inoculum (inocula) Spores, bacteria, or other living material which start disease infection in plants or animals.

Internode The region between the nodes, or joints, of the stem of a grass plant such as corn.

Mesocotyl The portion of the stem between the first and second node in the corn seedling (Fig. 20).

Micron A unit of length, .001 millimeter or .0004 inch. This sheet of paper measures about 80 microns in thickness.

Mycelium The cobwebby filaments forming the vegetative growth in fungi (Fig. 1).

Nodes The joints in the stem of a grass plant such as corn.

Oogonia Female reproductive organs in the lower plants such as fungi.

Oospore A spore resulting from a fertilized egg cell in certain fungi.

Open-pollinated A condition in which the floral arrangements are such as to permit the interchange of pollen among plants. In corn this is the normal process when not controlled by man.

Parenchyma Unspecialized thin-walled plant cells such as the pith cells in the cornstalk, or the cells which, with the exception of the veins, make up the bulk of the leaf tissue.

Pathogene An organism that is able to cause disease.

Pathogenic That quality in an organism by virtue of which it is able to cause disease.

Pericarp The outer membrane of the corn grain,—commonly called seed coat.

Perithecium A protective receptacle in certain fungi which incloses the asci (spore sacs), which in turn inclose the ascospores (Fig. 47).

Photosynthesis The process by which sugars and starches are formed from water and carbon dioxid in green leaves by the action of sunlight.

Phycomycetes A class of fungi that is characterized by the absence of septa in the mycelium except in the spore-bearing branches.

Physiologic strains Organisms that cannot be differentiated one from the other by their structure or appearance, but by their different reactions to their environment. Thus of two rust fungi which look exactly alike one is able to attack Kanred but not Kota wheat, the other attacks Kota but not Kanred.

Plumule The young shoot of the seedling.

Pure line The descendants from a single true-breeding plant propagated by self-fertilization. With some plants self-fertilization takes place naturally, but in order to obtain pure lines in corn, self-pollinations must be made artificially thruout a considerable number of generations. The term is only an approximation, for in corn an absolutely pure line probably cannot be attained.

Pycnidium A protective receptacle composed of numerous hyphae, inclosing the asexual spores of some fungi (Figs. 25, 26, 46).

Rachilla The small stub or branch to which each kernel of corn, or other cereal, is attached.

Saprophyte A living organism that uses only dead or decaying organic matter for food.

Scutellum That portion of the embryo which is next to the endosperm or starchy portion of the kernel. The scutellum is the dark, rotted region in Fig. 64, *C* and Plate III, *H*.

Seminal roots Roots that arise directly from the seed or embryo (Fig. 20).

Septum (septa) Cross walls in the spores or mycelium of fungi which form cell divisions (Figs. 1 and 30). A one-septate spore is composed of two cells, a two-septate spore is composed of three cells, etc.

Sorus (sori) Broken places on the epidermis of a diseased plant, exposing fungus spores which have developed underneath.

Sporangia In fungi, simple one-celled receptacles in which one to many asexual spores are borne (Fig 64).

Spore A one- or several-celled reproductive body produced by fungi and some of the other lower organisms. It has the function of seed in higher plants, but seeds are very much more complex in structure.

Sporulation The act or process of producing spores.

Stomata Microscopic openings in the epidermis of leaves and sometimes stems of green plants thru which gas exchange takes place.

Systemic disease A disease in which the causal organism spreads inside the growing host plant to all parts of it, usually following its main growing points.

Translocation The natural transfer of plant-food materials from one place to another in a plant.

Vascular bundle A group of tubes thru which water and soluble compounds pass from one place to another in plants. In the corn plant, each leaf vein and each strand in the stem is a vascular bundle.

Virescence In corn leaves a condition in which the leaves are at first nearly free of chlorophyl, but later are capable of producing chlorophyl in the presence of strong light. The green color development usually proceeds from the top of the leaf downward.

Virulence Power of an organism to produce disease.

Zoosporangia Sporangia containing asexual spores which possess cilia (hair-like outgrowths) by the movements of which they are able to swim about.

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