INTRODUCTION

The damping-off or wire-stem disease of cabbage (Brassica oleracea L.) seedlings, caused by the Rhizoctonia stage of Corticium vagum Berk. and Curt., has been known for a long time and has been studied critically by Gratz (4). For several years the writer has observed and investigated two other phases of Rhizoctonia injury to cabbage, known as bottom rot and head rot. The disease called head rot was first described by the writer (13) in 1927. In 1931 Weber (14) reported in abstract a Rhizoctonia bottom rot in Florida.

The present paper reports the results of studies of the cabbage-growing sections of Wisconsin, Indiana, and Illinois and parts of Iowa and Ohio. Each year from 1923 to 1928, inclusive, damping off, or wire stem, and bottom rot have been observed. Head rot, however, has been irregular in occurrence. It was seen first in 1923 and again in 1924. In 1925 it caused losses of 5 to 9 per cent in many fields in northeastern Illinois and southeastern Wisconsin. In 1926 it was less abundant, and in 1927 and 1928 fields were practically free from it.

DESCRIPTION OF RHIZOCTONIA ROTS OF CABBAGE

BOTTOM ROT

Usually there is little trouble from Rhizoctonia until the transplanted seedlings are large enough to begin to shade the ground. The disease first appears on the basal portions of the leaves next to the soil, the ventral side of the midrib often being the first part of the leaf attacked. The resulting lesions are sunken, black, and sharply elliptical, with their long axes parallel to the sides of the midrib. Round black spots appear on the basal parts of the leaf lamina, and these areas gradually enlarge. The diseased spots usually have over them sparse weblike surface mycelia. Eventually there is a general decay of the base of the leaf and the tissues become black and easily torn. The distal part of the leaf finally turns yellow, and the whole leaf droops, may dry up and drop off, and is often covered over by soil during subsequent cultivation. The Alternaria leaf spot (Alternaria brassicae (Berk.) Sacc.), which has been described by Weimer (15), may be confused with Rhizoctonia. The slowly growing...
lesion produced by the Alternaria becomes light colored and papery and is less extensive than the Rhizoctonia lesion. Rhizoctonia infects the bases of the leaves next to the ground first, whereas Alternaria attacks the upper surface of the tip and other distal points with equal facility. Rhizoctonia bottom rot is not necessarily followed by head rot.

**HEAD ROT**

Head rot (fig. 1) occurs spasmodically in the field under conditions as yet not well defined. If bottom rot occurs on a headed plant in the field and proper conditions prevail, such as high relative humidity and warm weather, hyphae of the organism grow along the stem without producing decay and infect other leaves farther up. These weaken the midribs and the leaves droop. If feces of cabbage worms lodge on the dorsal side of the petioles and on leaf blades, growth of the organism is stimulated and its head-rotting action is materially hastened. As the bases of the first cover leaves of the head are attacked, the exposed tips on top of the head turn yellow and tend to dry up. A few hyphae spread rapidly between the leaves of the head, and lesions are produced. The latter are mere punctations (fig. 2) at first, but later expand and coalesce and have scant strands of hyphae over them. The lesions are dark and sunken and have a suggestion of concentric zonation about a raised center at the point of infection. Hyphae may later grow out from such spots and produce numerous new lesions near the old. These diseased spots finally become confluent. If the weathered leaves on a diseased head are pulled apart a not unpleasant odor like that of boiled cabbage is noticed. As decay progresses, a weblike dark-colored mycelium develops between the diseased leaves. As the head rot advances only the leaf tissues are affected, while the stem and core of the head are not diseased. The head remains, therefore, conspicuous, upright, dark colored, and studded with small brown sclerotia.

The Corticium stage of *Rhizoctonia solani* Kühn is found early in the cabbage fields of Wisconsin and becomes more prevalent as the season advances. It occurs on the ventral sides of the lower leaves as a superficial gray or chalk-colored membranous growth, which can be easily stripped from its support. It is also found growing over the surface of the soil in protected places and attached to cabbage stems at the ground line.

**COMPARISON WITH OTHER HEAD ROTS**

The Rhizoctonia head rot differs from other head rots of cabbage in a number of details. The foliage leaves about an attacked head droop in a characteristic manner but may not drop completely from the plant. (Fig. 1, A.) The decaying tissues are more pliable and tough than those produced in watery soft rot or drop (*Sclerotinia sclerotiorum* (Lib.) Mass.) and in bacterial soft rot (*Bacillus carotovorus* L. R. Jones). In Wisconsin two head rots, one caused by Sclerotinia and one caused by Rhizoctonia, produce sclerotia. Rhizoctonia sclerotia are the smaller, the more irregular, and the more numerous. Rhizoctonia decay is neither slimy, as in bacterial soft rot, nor watery and translucent, as in watery soft rot and in head rot caused by species of *Pythium* (2). The infected tissues turn dark and shrink as they decay. In bacterial soft rot the odor of decay is
Rhizoctonia Bottom Rot and Head Rot of Cabbage

very noticeable, but in neither of the other head rots mentioned does the odor offend greatly. In Sclerotinia and Pythium rots the aerial mycelium is white and is most abundant in the former. (Fig. 1, B.)

Rhizoctonia upon infecting a mature cabbage head attacks only the leaf tissues, whereas bacterial black rot (*Bacterium campestre* (Fam.) E. F. Smith) is characterized by blackened vascular bundles. In cot-
tony rot, watery soft rot, and bacterial soft rot there may be decay of the stem.

THE CAUSAL ORGANISM

Isolation

Numerous isolations were made from cabbage seedlings affected with damping off and with wire stem, from leaves affected with bottom rot, and from heads affected with head rot. The Corticium stage of apparently the same organism was commonly found in the autumn on leaves showing signs of bottom rot and around the base of the plants. Four cultures were made from single spores and several

from bits of the mycelium of the hymenial layer. All these cultures when compared with cultures known to be those of *Rhizoctonia solani* and with descriptions by Kühn (5), Duggar (3), Matsumoto (7), and Burt (1), were found to belong to this species.

Pathogenicity

Numerous cultures from the sources listed above were used in inoculation experiments upon cabbage plants at various stages of growth, including 15 to 20 flats of young seedlings, a large number of partly grown potted plants, and over 200 cabbage heads, some growing in the field and some cut and placed under bell jars in the laboratory. The results of each experiment were checked with control
Rhizoctonia Bottom Rot and Head Rot of Cabbage

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plants. The inoculations were generally successful. All strains produced typical damping off of the seedlings, bottom rot of older plants, and typical head rot of heads approaching maturity or already harvested. The results showed conclusively that bottom rot and head rot are caused by the strains of the imperfect stage of the fungus Corticium vagum isolated from cabbage. They show furthermore that the causal organism is identical with that causing the Rhizoctonia damping off or wire stem of cabbage seedlings.

PHYSIOLOGIC SPECIALIZATION OF RHIZOCOTONIA STRAINS

Physiologic specialization in fungi, in which certain morphologic species are subdivided into forms exhibiting distinct parasitic specialization, is a well-known phenomenon. It has been studied in Rhizoctonia solani by several workers, the most important contributions being those of Duggar (3), Matsumoto (7), and Peltier (10). The physiologic reactions of strains of the fungus in pure culture as a measure of biologic specialization has not yet received adequate attention; the pure-culture work of Matsumoto (7) and of Monteith and Dahl (9) are thus far the most important contributions to this problem.

Physiologic specialization of Rhizoctonia solani on crucifers has received only incidental attention. Peltier (10) found that a strain isolated from cauliflower, though able to infect seedlings of a fairly wide range of host plants, appeared to attack the Cruciferae most severely. Gratz (4), studying strains isolated from a number of host plants, found that the Rhizoctonia causing wire stem of cabbage was probably pathogenic on that plant only, and that the typical potato Rhizoctonia did not cause wire stem of cabbage. Van der Meer (8) found that strains of Rhizoctonia obtained from potato and cauliflower "were physiologically distinct from each other." Lauritzen’s (6) study of Rhizoctonia rot of turnips showed that the potato and turnip strains were pathogenic only on the hosts from which they were isolated. The question of physiologic specialization inevitably presented itself in connection with the present study of Rhizoctonia causing bottom rot and head rot of cabbage.

Sixty-nine isolations of Rhizoctonia from a number of hosts were studied. In this discussion the data from only 15, representing isolations from 6 different hosts, will be considered. The results of comparative inoculations at various stages in the development of cabbage, potato, and lettuce are summarized in Table 1. It is to be noted that the cabbage isolations were practically nonpathogenic to potato and that the potato isolations were nonpathogenic to cabbage. This is in accord with the results of Gratz (4) and of Lauritzen (6) noted above, indicating that isolations of Rhizoctonia from cruciferous hosts were rather specific to those plants. Isolations from bean, beet, pea, and lettuce likewise failed to cause head rot or bottom rot of cabbage, although that from lettuce did cause damping off of small cabbage seedlings. On the other hand, all the cabbage strains were fairly pathogenic to lettuce. These results, though limited, indicate that only certain strains of Rhizoctonia solani are capable of causing head rot and bottom rot of cabbage.
Table 1.—Specialized pathogenicity of certain representative strains of Corticium vagum

<table>
<thead>
<tr>
<th>No.</th>
<th>Host from which obtained</th>
<th>Disease on host</th>
<th>Results of inoculations a</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>On cabbage</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Head rot</td>
</tr>
<tr>
<td>1</td>
<td>Bean</td>
<td>Root rot</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>do</td>
<td>-</td>
<td>-</td>
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<tr>
<td>3</td>
<td>Beet</td>
<td>Dry rot</td>
<td>-</td>
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<tr>
<td>4</td>
<td>Pea</td>
<td>Root rot</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Lettuce</td>
<td>Bottom rot</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>do</td>
<td>Head rot</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Potato</td>
<td>Sclerotia on tuber</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>do</td>
<td>Stem lesion</td>
<td>-</td>
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<tr>
<td>9</td>
<td>do</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>do</td>
<td>-</td>
<td>-</td>
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<tr>
<td>11</td>
<td>Cabbage</td>
<td>Head rot</td>
<td>-</td>
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<tr>
<td>12</td>
<td>do</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>do</td>
<td>Wire stem</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>do</td>
<td>Damping off</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>do</td>
<td>Corticium over stem</td>
<td>-</td>
</tr>
</tbody>
</table>

a + indicates infection; - indicates no infection.

b Sclerotia small and few in number.
ENVIRONMENT IN RELATION TO DISEASE PRODUCTION BY THE
CABBAGE RHIZOCTONIA

MOISTURE RELATIONSHIPS

In his studies of damping off Gratz (4) found that Rhizoctonia required a high moisture content of the soil. Either drought or excess of water in the soil hindered the development of the disease. The writer's observations corroborate these findings.

To determine the effect of relatively high and low moisture content of the air on the Rhizoctonia producing bottom rot and head rot, a number of experiments were performed. Heads of cabbage obtained on the Madison, Wis., market were taken as host material, and two strains of the fungus were used. After the outer leaves had been carefully removed under aseptic conditions, inoculations at seven points on the top of each head were made from Rhizoctonia cultures. The inoculum consisted of surface sclerotia and bits (about 1 cm square) of the culture medium covered with young growing hyphae. Half of the inoculated heads were placed under bell jars and half were left uncovered in the comparatively dry laboratory air. The temperature of the room was about 21° C. Under the bell jars fungal hyphae could be noted within 24 hours, extending out from sclerotia and bits of agar culture, and in three days the leaf tissue showed symptoms of attack and the organism developed rapidly. Release of water from the host tissue appeared much accelerated with increased decay, water drops gathering in much greater quantities on the inside of bell jars over decaying heads than over uninoculated individuals. On the uninoculated heads left uncovered the inoculum dried up and no Rhizoctonia decay resulted.

Plants growing in sterilized soil in the greenhouse were likewise used in determining the relation of moist atmosphere to disease production. These plants, of an early variety of cabbage, had grown rapidly and were forming small heads. Greenhouse temperatures ranged between 18° and 24° C. Inoculations were made with young sclerotia from pure cultures of a cabbage head-rot strain of Rhizoctonia. Inoculum was placed in the forming head and on foliage leaves. Controls were inoculated with bits of sterile agar. The soil was kept wet and some of the plants were covered with a glass-sided box, and others were left uncovered. The Rhizoctonia organism produced typical head rot and bottom rot on all the inoculated plants kept under the moist chamber; a few unprotected plants inoculated in the forming head showed signs of becoming diseased, though the symptoms were not advanced. It appears that a very humid atmosphere is most conducive to the progress of both diseases and is particularly important for the development of head rot.

TEMPERATURE RELATIONSHIPS

Richards (11), in 1921, reported studies on the relation of soil temperature to injury of potato stems by Corticium vagum (Rhizoctonia solani). He found that the organism caused lesions over a wide range of temperatures (9° to 27° C.), that the optimum temperature for pathogenicity was 18°, and that above 24° Rhizoctonia was not a serious factor in disease production. In 1923, he (12) again reported studies of Rhizoctonia, this time on pea and bean. As before, he found that temperature had a very definite effect on disease produc-
tion. No infection occurred below 9° or above 29°. The optimum may be placed at 18°. In pure culture the range differed, the minimum temperature for growth being 4.6°, the optimum from 25° to 27°, and the maximum 32.6°. Gratz (4), in 1925, found that Rhizoctonia damping off of cabbage had quite definite temperature relationships. The minimum for disease production was below 10°, the optimum from 15° to 30°, and the maximum from 31° to 32°. In pure culture the organism grew at a minimum of approximately 9°, an optimum between 22° and 26°, and a maximum of slightly above 31°. In 1928, Monteith and Dahl (9) reported temperature relationships of pure cultures of nine strains of *Rhizoctonia solani* from grass, pea, and potato. In general these strains grew at a minimum temperature of less than 10°, an optimum of 25° to 30°, and a maximum of 35°.

Temperatures determined by the writer for the organism causing bottom rot and head rot of cabbage are practically the same as those found by Gratz (4). In pure culture on potato-dextrose agar the cabbage Rhizoctonia produced growth at 8°C. At 9° the fungus grew very slowly. Between 12° and 22° rapidity of growth increased enormously. The most rapid growth was above 23° and below 27°. At 29° the rate of growth was materially lessened, at 30° it dropped still further, and at 33° no growth occurred. General field observations indicated that Rhizoctonia was most active during warm weather. Headed plants were potted, inoculated with sclerotia from pure cultures of Rhizoctonia causing head rot, and placed in greenhouses at temperatures ranging from 10° to 33°. Inoculated heads decayed slowly at a temperature of 12°. At 15° to 20° the disease developed at a slightly more rapid rate. At 21° to 23° disease production was further enhanced. The optimum temperature for head rot was determined to be from 23° to 27°. Above 30° decay was considerably lessened, and at 32° there was none.

In a further study of temperature relations, bleached leaves aseptically removed from the inside of heads of market cabbage were put in sterilized moist chambers and inoculated with pure cultures of two strains of Rhizoctonia obtained from cabbage plants affected with head rot. The moist chambers were then held at constant temperatures. Temperature relationships for decay were the same as previously determined, except that the minimum temperature was placed at about 9°C and the optimum temperature narrowed down to between 25° and 27°.

**SUMMARY**

The present paper describes two diseases of cabbage, Rhizoctonia bottom rot and head rot, and presents the results of recent studies on both of these diseases, which are caused by *Rhizoctonia solani* Kühn, the imperfect form of *Corticium vagum* Berk. and Curt. Bottom rot attacks cabbage every year, but head rot is spasmodic in its occurrence. It was proved by isolation and inoculation experiments that these two diseases of older plants in the field are caused by the same strain of Rhizoctonia that produces damping off, or wire stem, of cabbage seedlings.

A number of strains of *Rhizoctonia solani* were obtained and studied for evidence of physiologic specialization. It appears that strains of the organism are most pathogenic upon the hosts from which they were originally isolated.
Environmental factors were studied in relation to disease production. It was found that a relatively large amount of moisture is necessary for optimum disease production by the fungus. Rhizoctonia bottom rot and head rot were produced at temperatures ranging from 9°C to somewhat less than 32°C. The optimum temperature for disease development is between 25°C and 27°C.

LITERATURE CITED

(1) Burt, E. A.

(2) Drechsler, C.
1925. PYTHIUM INFECTION OF CABBAGE HEADS. Phytopathology 15:[482]-485, illus.

(3) Duggar, B. M.

(4) Gratz, L. O.

(5) Kühn, J.
1858. DIE KRANKHEITEN DER KULTURGEWÄCHSE, IHRE URSACHEN UND IHRE VERHÜTUNG. 312 p. Berlin.

(6) Lauritzen, J. I.

(7) Matsumoto, T.

(8) Meer, J. H. H., Van Der.

(9) Monteiith, J., Jr., and Dahl, A. S.

(10) Peltier, G. L.

(11) Richards, B. L.

(12) ———

(13) Walker, J. C.
1927. DISEASES OF CABBAGE AND RELATED PLANTS. U. S. Dept. Agr. Farmers' Bul. 1439, 30 p., illus. (Section on Rhizoctonia Head Rot prepared by F. L. Wellman, p. 29.)

(14) Weber, G. F.

(15) Weimer, J. L.