STUDIES IN CEREAL DISEASES

III

SEEDLING BLIGHT AND FOOT-ROTS OF OATS

Caused by Fusarium Culmorum (W.G. Sm.) Sacc.

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SEEDLING BLIGHT AND FOOT-ROTS OF OATS CAUSED BY FUSARIUM CULMORUM (W.G. Sm.) Sacc.*

INTRODUCTION

Grain crops in Western Canada are often afflicted with a disease commonly referred to as root-rot or foot-rot. Unlike the rusts and smuts which are usually conspicuous, root-rot diseases are very variable in their symptoms. Consequently their initial stages are often overlooked or the abnormal condition is attributed to drought, wind, frost and so forth. From seeding to harvest, the plants are exposed to these diseases and in a large measure their incidence is determined by the prevailing weather conditions. An unfavourable period at any time during this season may mean an increase in disease development. It is obvious then, that the investigator must be acquainted with the various manifestations of the disease throughout the season as well as have some knowledge of soil conditions. This directs the study into the vast and complex field of soil microbiology. Of the many organisms which may be found in the soil or on crop debris, fungi appear to be most commonly associated with root- or foot-rot diseases of cereals.

In the summer of 1921 a severe root and stalk-rot of oats was brought to our attention. Preliminary observations and tests served to demonstrate the fungus *Fusarium culmorum* (W. G. Smith) Sacc., as the causal parasite; later, studies which are reported here, confirmed in a large measure the earlier conception. Although other fungi were found associated with similar diseases of wheat, oats and barley, it was, however, necessary to somewhat limit our efforts in order that some of the details could be worked out.

It has been the intention to study this disease as carefully as possible in order to obtain some knowledge relative to its mode of development, the extent to which the crop may be damaged, and in regard to possible means of control.

THE DISEASE

HOSTS

It is difficult to give a sharply defined host range, as the fungus under consideration may readily live as a saprophyte, and at times its relationship with the host is of a doubtful parasitic nature. On cereals and grasses in general, two distinct types of disease are manifest, a head blight and a foot-rot condition, including seedling blight. In the latter type the most severe manifestation is revealed by oats. For early reports of this disease on oats we may note Johnson (18), and Selby and Manns (32). Reports of similar diseases on wheat and other cereals are by Akermann (1), Rose (27), Doyer (15), Dounin (14), Guyot (17), Appel (2), Peyronel (26) and Erhard-Frederiksen (16). When the same organism may be considered in its association with tuber and fruit rots the host range can be greatly extended (Wollenweber (41)). The fungus was also isolated from an apparent stalk-rot of corn, and it is believed that it may constitute a serious menace to seedling corn once this

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crop is more widely grown in Western Canada. Diseases of this nature appear to be particularly dependent upon the environment for their initiation and development. Under favourable conditions for disease, all of the leading cereal crops may be severely affected. Experiments dealing with the influence of environment will be discussed later.

GEOGRAPHICAL DISTRIBUTION

This disease has been reported particularly from the United States and Canada. It is probably more common than supposed, and can be expected to occur in all the leading cereal producing countries. Reports of a similar root-rot of cereals, although oats have not been mentioned specifically, have come from the following countries,—Russia, Germany, Sweden, Denmark, Holland, France and Italy. In the United States the distribution of a similar disease of wheat, as well as head blight of this and other hosts, appears to be chiefly in the Northern and Pacific Coast States. In the cereal growing regions of the Central States of the Union such diseases are prevalent, but as a causal organism *Fusarium culmorum* is less commonly found than *Gibberella Saubinetii*. There appear to be some geographical limits in the distribution of these fungi, and the diseases which they cause; *F. culmorum* ranging northward and *G. Saubinetii* to the southward in the Central States, which may be due to the methods of farming practised in the two territories, or ecological factors generally may play a role. In this connection it is of interest to note the reports of this type of disease from Northern Europe.

ECONOMIC IMPORTANCE

If it is true that *F. culmorum* is most common in the northern countries, and when it is taken into consideration that such countries are leading in oat production, then the possible economic importance of this disease becomes apparent. In most countries diseases of wheat are given more attention than those of other cereals, consequently there are very few specific reports of damage to the oat crop by this disease. Furthermore, one should consider the difficulties involved in diagnosing such diseases, and how readily they may be confused with other troubles, as frost, drought and poor soil conditions. Johnson, 1914, reports on a ten acre field of oats in Ohio practically destroyed by this type of disease; the same investigator noted a marked virulence in the attack on oats as compared with wheat and barley. Appel, 1925, in a study of various seedling blights of cereals, considers *F. culmorum* as the most virulent of the fungi observed. Careful observations were made for the last five years in the grain fields of Western Canada, and from diseased oats, *F. culmorum* has been commonly isolated. It is believed that this fungus is in many cases one of the causal factors, and often the principal one. Under greenhouse conditions the disease may cause a loss of from seventy-five to one hundred per cent. Such percentages very seldom prevail in the field, but the virulence of the fungus, its common occurrence and remarkable adaptability, draws attention to probable serious losses in the field.

SYMPTOMS

This disease, like others of this group, cannot be diagnosed readily under field or greenhouse conditions. Various fungi, as well as dry soil and high temperatures, may cause lesions on the basal parts of the oat plant similar to those resulting from the attacks of the causal fungus. A careful examination of many diseased seedlings from inoculation experiments, as well as diseased plants collected at random in the field, leads one to group the symptoms as

follows: (1) Pre-emergence blight, which is an invasion of the young plant after germination, resulting in complete killing, so that the affected seedling does not appear above ground. This phase of the attack is naturally seldom noticed in the field unless a careful search is made; it results in a reduced stand. (2) Seedling blight, which occurs after germination, i.e. some time after emergence. The leaves fall over and turn brown, being killed by the invasion below. The invaded portions, which include the coleoptile and mesocotyl (fig. 2), will reveal dark brown lesions. The roots likewise, if invaded, may be brownish in

FIG. 1.—Showing pre-emergence blight, seedling blight, severe and slight lesions of the mesocotyl region of oats.

colour and poorly developed. Under conditions of high humidity, the fungus will grow readily from all invaded parts. (3) Invasion of the mesocotyl region and adjacent parts. Sometimes a seedling will show only slight or small lesions on the mesocotyl and coleoptile, which do not interfere greatly with normal development. If, however, the conditions are favourable for the fungus, the entire cortex of the mesocotyl and coleptile will be invaded. This may become serious when the crown is invaded, resulting in a killing of tiller buds and root initials, producing an under-developed plant with few tillers. Such plants attract attention in the field, and a careful examination will reveal the necrotic mesocotyl and coleoptile. If the invasion does not reach the crown, roots will appear, and although the seminal roots and mesocotyl are invaded, the plant will develop in a manner nearly normal.

The first two phases of the disease almost inevitably result in the death of the seedling, the third form depends on environmental factors as to whether it will be of consequence or not. In thickly sown fields, and under humid conditions, lesions may extend up the stem some distance, ultimately killing the plant. The fungus will readily sporulate on such affected parts (fig. 1).

PATHOLOGICAL ANATOMY

Preliminary studies were made of the pathological anatomy in connection with this disease. In the early studies, preparations were made from plants showing lesions and in this way some understanding of the mode and extent of the invasion was obtained. Later these studies were carried further. In the experiments on soil temperature and moisture, plants showing typical lesions were selected for study. Appropriate pieces were fixed and prepared in the ordinary way for sectioning. Most of the advance stages of the invasion were obtained from this source. Finally an endeavour was made to determine the mode of penetration, and the early stages of the invasion.

METHODS

In cases where distinct lesions were taken, comparable ones were plated out to correlate the presence of the fungus with the lesions being studied. Medium chromo-acetic fixing solution was used for most of the early work, later formo-acetic-alcohol was used more commonly. There appears to be no satisfactory fixing preparation for both host and fungus tissue. In this work, however, these reagents were quite satisfactory, as merely the general histological phases were being considered. In studying penetration, small pieces of the epidermis were stripped off, fixed, stained and mounted in glycerine. Gentian violet, safranin and Pianeze were the stains commonly used.

Banner and Victory oats were used in practically all of the work. As far as could be determined from preliminary tests these two varieties react in a similar manner when inoculated. In studying penetration, seeds were prepared for inoculation by surface sterilization with semesan. They were germinated on filter paper in clean moist chambers; when the mesocotyl and coleoptile were distinct, inoculations were made on definite areas marked with India ink. Conidia were placed on the epidermis by means of a needle when taken directly from sporodochia, or with a glass rod when a conidial suspension was used. Usually conditions remained sufficiently moist for germination and penetration. It was found to be advantageous to place some inoculation chambers at 18 degrees, to prevent too rapid development. Such preparations were studied at intervals from 12 to 72 hours, and the various stages of progress observed. In handling the material for permanent or temporary mounts, it was difficult to prevent the conidia from being washed away.

An outline of the morphology of the oat seedling is necessary for an explanation of the pathological anatomy. The oat seedling germinates in a manner similar to that of other grasses. The primary seminal root is the first to emerge, breaking through the coleorhiza, which elongates slightly during this period; soon three other seminal roots emerge. By this time the plumule appears unsheathed by the coleoptile. Then elongation, which serves to bring the plumule to the surface of the soil, takes place in the mesocotyl region which extends between the base of the coleoptile and the scutellar node or cotyledonary node. The seminal roots arise from the cotyledonary node. Opposite the scutel-

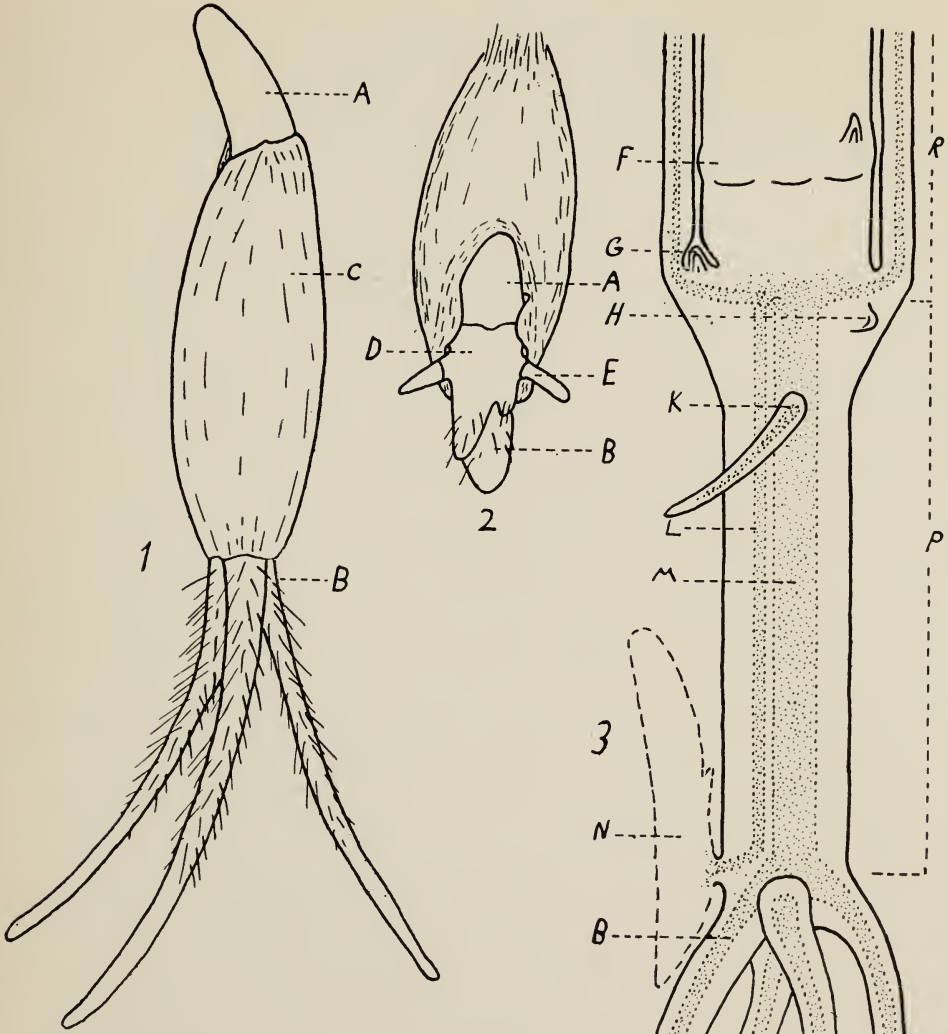

FIG. 2.—Showing various stages and structures in the development of the oat seedling. 1. Early stages in germination. (A) Coleoptile encasing the primary bud; (C) lemma; (B) primary and two lateral seminal rootlets. 2. Early stages in germination with the "hull" removed. (A) coleoptile; (D) coleorhiza; (E) lateral rootlet; (B) primary rootlet. 3. A diagram of the basal part of a seedling three weeks old. (F) second nodal region; (G) tiller bud in the axis of the coleoptile; (H) primordium of a nodal root; (K) cauline root; (L) scutellum trace; (M) stele; (N) scutellum; (B) primary rootlet; (R) base of the coleoptile; (P) mesocotyl region.

lum is the epiblast, and immediately below it, surrounding the primary root and secondary seminal root initials (in the embryo stage), is the coleorhiza. In this region the vascular system of the main axis separates and extends downward into the roots, the main stele is continuous into the primary root. In the mesocotyl, the main stele as well as a small vascular trace which comes from the scutellum are clearly defined. This bundle trace does not join the main vascular system until it reaches the first node. At the first node there are two distinct bundles branching into the coleoptile. Very early in the development of this node two roots are initiated opposite each other. Soon other roots appear, as well as a tiller bud in the axis of the coleoptile. The vascular system in the first true internode is complicated by the numerous leaf traces. At the next node several roots are initiated, as well as a tiller bud in the axis of the first true leaf. The oat is similar to corn in that the mesocotyl is the principal region of elongation; it differs in having a scutellum trace distinct from the main vascular system. In wheat the first true internode is the region of elongation, and consequently is covered by the coleptile, whereas in oat the zone of elongation, the mesocotyl, is naked (fig.2).

PENETRATION

The conidia germinate readily when placed on the coleoptile or mesocotyl. The germ tube may run for some distance over the surface, or on the other hand it may be very short. The areas where epidermal penetration was initiated could be determined by the different staining reaction. When Pianeze stain was

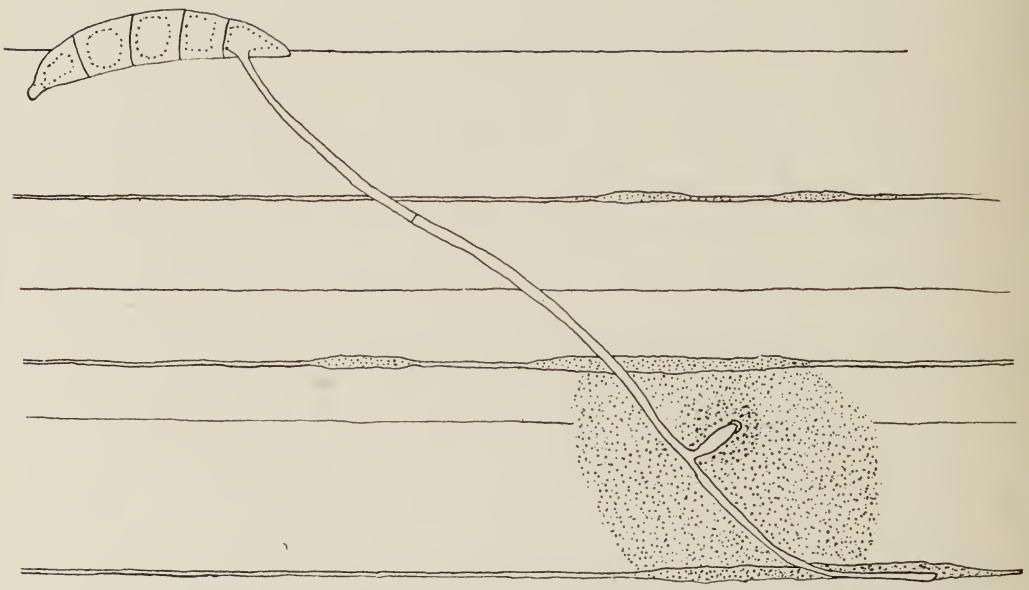

FIG. 3.—Surface view of a strip from the epidermis of the mesocotyl showing an incipient stage in penetration, cell wall reaction and swellings of the cell walls x 500.

used with fresh preparations dark green areas indicated the penetration points. Gentian violet stained the walls deep violet in a like manner. A germinated conidium of the fungus with germ tube penetrating the cell wall is shown in figure 3. There were numerous conidia of the parasite in this penetration, with germ-tubes running here and there over the surface in various early stages of penetration. Although there were many cell wall swellings in this region only

one infection point was distinct, which is the one used for illustration. This gives the stage of development on the mesocotyl after 72 hours at 18° C. The germ tube in this case was branched at the tip. A small branch was attached in an area which had the appearance of a probable penetration point. The main branch had continued along above the union of two cell walls which show distinct swelling. At the penetration point, the imediate area beneath the hyphal tip has taken the stain deeply, while in the centre there is a distinct bright, but very small spot, which is probably the actual penetration point. Outside the deeply stained area is a faintly stained zone relatively large in extent, showing cell wall reaction. The swellings of the cell walls on either side of this region and around it, the writer believes, are not directly associated with this point in particular, but have been produced by other conidia. Observations on similar locations appear to confirm this interpretation. A similar early stage is noted in a longitudinal section made from a permanent mount of the same region as above, but from a seedling grown at 24 degrees for 36 hours (figure 4). Here the swollen tip of the hypha or appressorium had developed over a junction of vertical walls. This germ tube came from a conidium which was not well located for illustration. This slide had been stained with Gentian violet and safranin, then destained to the required depth. At the penetration locus the outer edge of the reaction zone took a bright red, the immediate inner zone was distinctly

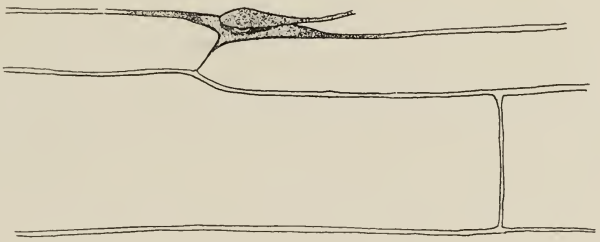

FIG. 4.—A longitudinal section from the mesocotyl showing a similar penetration point as that illustrated in Figure 3 x 500.

less brilliant, showing a change in the refraction of the light indicating a modification of the cell wall. Inside of this zone, and just under the appressorium, was a darkly stained area comparable to the one in figure 3, and in the centre a small bright spot was distinctly visible (plate 1, F). There appears to be little doubt of a change in the cell wall, which it is believed takes place soon after the appressorium is formed and becomes attached to the cell wall. It seems that preparatory to penetration, the cell wall, in cases where the appressorium is directly over a vertical wall, becomes swollen, probably assisting in a cleavage, and as very little cuticle would be formed at this stage the entrance of the penetrating hypha is thus facilitated. The change in the cell wall extending for some distance around the penetration point has been noted consistenly in these studies, also when the hyphae runs along the surface there appears to be some reaction beyond and around it, if differences in cell wall is any indication. It appears that the conidia and their germ-tubes, in the process of penetration, lose their contents as the internal hyphae develops into the tissue. Consequently several days after inoculation many penetration points and internal hyphae can be seen, yet the direct connection of these internal hyphae with the exterior is not so commonly evident. This is particularly true when permanent mounts are made. The writer has noticed that after inoculation, especially when a mass of conidia were placed on the host, infection was rapid and at so many points that individual penetrations could not be determined. Infections of this type, it is believed, are of most consequence in nature. For example, a mass of mycelium

established on some bit of debris, or in the case of oats, perhaps on the hulls, rapidly spreads over the growing tissue of the mesocotyl and coleoptile and result in a short time in a mass penetration. In using masses of conidia for inoculation purposes, this type of penetration appeared to be common. The conidia germinate, and the resulting hyphae forms strands or masses on a region of the epidermis. The cell walls become greatly altered and many penetrating hyphae are seen immediately beneath this mass; the subsequent development is very rapid (figure 5). It is reasonable to expect that if one germ-tube in the act of penetration can alter the cell wall so markedly, a number of germ-tubes may have the same effect on a larger scale. As the cortical cells are killed, the hyphae accumulate and ramify extensively. There appears to be very little difficulty in penetrating the internal cell walls, although at such points swellings of the hyphae and constrictions in passing through the wall can be seen (plate

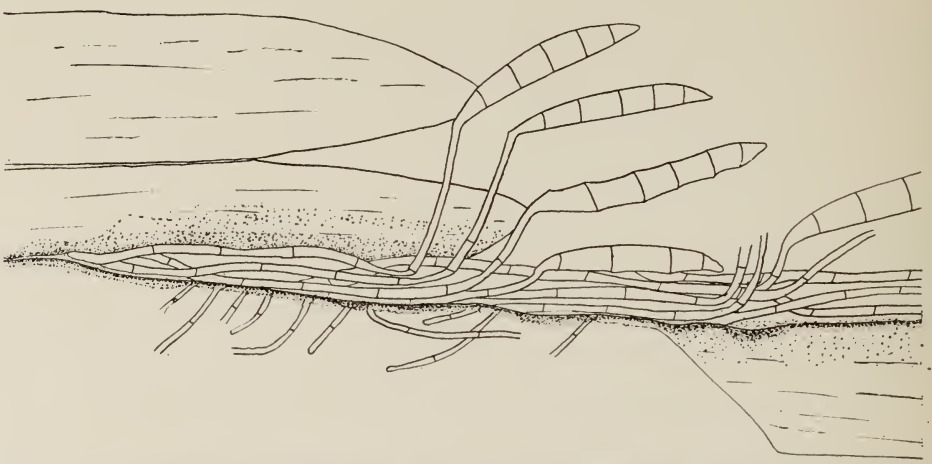

FIG. 5.—A diagrammatic drawing of a mass infection surface view. The germ tubes from several conidia are massed together above an epidermal cell wall which appeared somewhat altered. Several hyphae have broken through., x500.

1, B, D). Callosities described by Stevens (36) for *Helminthosporium sativum* infection of wheat, and Young (44, 45) in penetration studies with various fungi, have been noted in this study. Callosities in the coleoptile of Banner oats inoculated with conidia are shown in plate 1, E. What appears to be penetrating hyphae can be distinctly seen in these callosities, under high magnification, but their exact connection with the fungus considered here has not been determined. In another case where the mesocotyl was inoculated with mycelium, numerous characteristic callosities were formed. In this case a piece of the mesocotyl was stripped off and mounted in glycerine without staining. They appear yellowish green in colour with transmitted light, which is essentially the same light absorption as obtains in the cell wall. It is probable that callosity formation is associated with penetration of this fungus, but it does not appear distinctly in every case. There is a possibility that temperature relations determining host reactions, or the age of the culture at inoculation time, may have a bearing upon their formation.

CORTICAL INVASION

The fungus appears to develop rapidly between and in the cells of the cortex, the hyphae is much branched and running in all directions (plate 1, B, D). In the region of the endodermis, however, the invader apparently meets with some resistance, for very rarely is the stele invaded. The hyphae are more compactly branched, sometimes massed in the vicinity of the vascular system, and often greatly swollen. This is particularly well shown in the early invasion of the

coleoptile where the mycelium has collected around the vascular system, and large swellings result in this region (plate 1, C). The extent of the invasion, as well as its relation to the conducting tissue, is determined in transverse sections of the mesocotyl. The mycelium is often well developed and abundant in the cells from the epidermis of the cortex to the endodermis, as well as in the scutellum bundle trace (plate 2, D). About one-half of the scutellum trace at this point is completely invaded, as well as the cortex immediately adjacent. The main vascular bundle, however, is not invaded or at least to only a slight extent. As long as the stele remains intact the seedling usually develops in a normal manner. Many times the mesocotyl will show severe lesions without the plant showing any ill effects. As the fungus develops rapidly in this region the entire cortex of the mesocotyl may be invaded and killed. It is believed that as the fungus accumulates near the vascular bundles these tissues are altered in such a manner that they are then subject to invasion. The fungus may invade any region of the cortex of the mesocotyl and go from there into the roots or crown. The most severe early invasions of the crown probably result from entrance through the coleoptile or through ruptures made by the emerging crown roots. The coleoptile is readily infected while young. The fungus develops readily in the space between the plumular tissue and the coleoptile. In the very young seedling this type of invasion terminates in pre-emergence or seedling blight. If the seedling survives it may have a severe invasion of the crown, including the first and second nodes. The fungus in this region attacks the root initials, sometimes completely invading the newly formed cortical cells (plate 2, C). In plate 2, B, an early invasion of a root initial is seen, the fungus has completely invaded the base of the first leaf and is passing on into the root as shown by the altered tissue. The affected cells have no definite form, and the entire group shows a deeply stained mass of cell contents. A similar situation is seen where a tiller is affected (plate 2, A). A mass of mycelium occurs between a part of the base of the first leaf and the outermost fold of the tiller bud. The effect of the invasion on the inner tissues of the bud can likewise be seen. Mycelium has massed, moreover, in the crease between the tiller bud and an adjacent root.

One artificial inoculation of the seminal roots, soon after their emergence, shows a severe infection. The hyphae particularly invaded the cortex. There was some indication of the infection being made through the root hair. The fungus was found in root hairs (plate 1, A), but it could not be definitely determined from the preparations at hand whether penetration had actually occurred in this manner. It is believed that penetration may occur in this way or directly through the epidermis, as with the mesocotyl or coleoptile. Examinations of plants collected from the field will frequently show hyphae in the root hairs, but the identity of the mycelium has not been determined.

The above observations give one a clearer understanding of the various aspects of the disease. The seminal roots, the coleorhiza, and the coleoptile may be readily attacked in the early stage, causing pre-emergence blight or seedling blight. Later the mesocotyl and coleoptile may show the most conspicuous lesions with an invasion of the crown, which can be particularly referred to as a foot-rot. A true root-rot type of invasion also occurs.

THE CAUSAL ORGANISM

TAXONOMY

Fusarium culmorum was first described by Worthington G. Smith (35) and named *Fusisporium culmorum*. Saccardo (28) lists *Fusarium culmorum* (W. J. Smith) Sacc. The name as now accepted is *Fusarium culmorum* (W. G. Smith) Sacc. Later it was described by Appel and Wollenweber (3) as *Fusarium rubiginosum*, but this name is now relegated to synonymy. It has

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often been confused with the Fusarium stage of *Gibberella Saubinetii* (Mont) Sacc. (*F. graminearum* Schwabe). *Fusarium roseum* is a collective species name which has been given species of the *F. culmorum* and *G. Saubinetii* types, but which no longer ranks as a species name.

The species differences between *F. culmorum* and *G. Saubinetii* should be kept in mind when a study is being made of cereal diseases in which either of these fungi are concerned. A constant difference between the two is the presence of chlamydospores in *F. culmorum,* while they are lacking in *G. Saubinetii.* This is probably the most reliable distinguishing difference, for although there are differences in size, shape and septation of conidia, careful culture work is needed before such differentiation can be made. Other species of Fusarium often isolated from cereals, and which somewhat resemble the above, can in most cases be readily distinguished. Wollenweber (42) describes *F. culmorum* as follows:—

"*Fusarium culmorum* (W. G. Smith) Sacc.

"*Fusisporium culmorum* W. G. Smith, 1884. Diseases, Field and Gard. Crops, p. 208-210, fig. 92.

"*Fusarium Schribauxi* Delacr., 1890, Bul. Soc. Mycol. France, t. 6, fasc. 2, p. 99, pl. 15, fig. 1; Sacc., 1892 Syll. Fung. V. 10, p. 726.

"*Fusarium culmorum* (W. J. Smith) Sacc., 1895, Syll. Fung., V. 11, p. 651.

"*Fusarium corrallinum* Mattirolo (non Sacc.), 1897, Mem. R. Accad. Sci. Ist. Bologna, s. 5, t. 6, p. 677, fig. 16-17.

"*Fusarium rubiginosum* App. and Wollenw., 1910, in Arb. Biol. Anst. f. Land. u. Forstw., Bd. 8, Heft 1, p. 108, pl. 1.

Diagnosis.—"Conidia scattered in sporodochia or in pionnotes in masses, ochreous to salmon coloured, 5 septate, averaging 30 to 45 by 5·5 to 7u, seldom 3 to 4 septate, rarely with a larger or smaller number of septa. The slight constriction at the apical end, and the pediellate base of normal conidia, make this fungus a type species of the section discolour. Conidiophores in sporodochia increase to repeatedly verticillate ramifications, with sterigmata and side branches as many as four in whorls. The mycelium thallus has a yellow acid

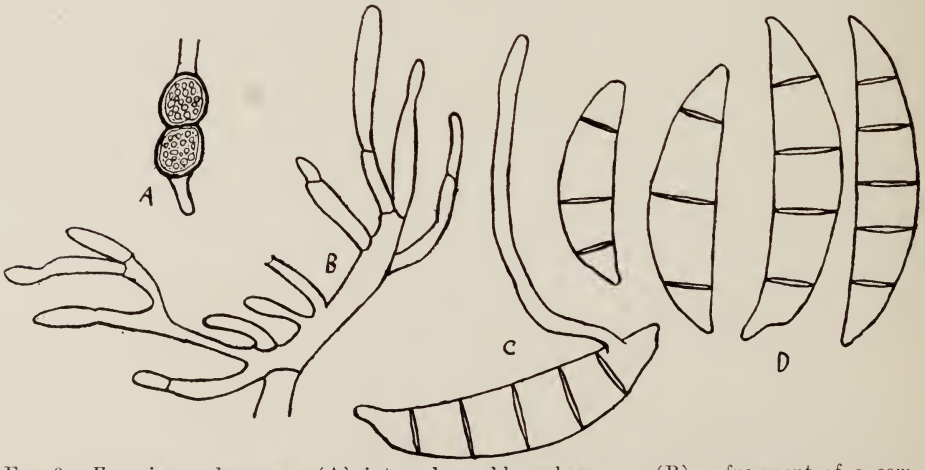

FIG. 6.—*Fusarium culmorum.* (A) intercalary chlamydospores; (B) a fragment of a compound conidiophore; (C) a germinating conidium; (D) various types of conidia, the five septate ones are most common. x 1,000.

modification (viz. on rice), turning violet with alkaline; and a carmine red basic one (viz. on wheat and potato tubers), turning yellow with acid. Chlamydospores intercalated, single, in chains or in clusters, averaging 7 to 14 u in diameter."

Habitat.—" This species is found in Europe and North America on all parts of partly decayed plants. It is a wound parasite on cereals and causes scab and seedling blight (foot disease). It has been found on the following hosts,—*Zea, Avena, Triticum, Secale, Hordeum, Lupinus, Gossypium, Ipomoea, Beta, Solanum, Cucumis, Curcurbita* and others."

CULTURAL STUDIES

Temperature.—A series of plate cultures were run at temperatures varying from 4° to 36° C. In the first series potato dextrose agar + 10 (Fuller's scale) was used, approximately 20 cubic centimeters per plate. Each plate was inoculated in the centre with a suspension of a density of 7,000 to 9,000 conidia per c.c., made from slant cultures two or four weeks old. By means of a definite size needle loop the same amount of inoculum was used for each plate. Two plates were run at each temperature for each series, and in all five series were studied. At the high temperatures the plates were kept in a moist chamber to prevent undue drying. In the second series oat agar was used which titrated + 2 (Fuller's scale). The conidia for inoculation were taken from cultures one to two weeks old. The general method and manipulation was the same as described for the first series in all five series run. The amount of growth was determined by measuring the diameters of the colonies. The average comparative results of both series are given in table 1 and figure 7.

Table 1.—Influence of Temperature on the Vegetative Development of *F. culmorum on* Potato Dextrose Agar and Oat Agar

Medium	Number of tests	Age of culture (days)	Average diameters of the colonies in centimeters at temperatures of—								
			4°	6°	13°	16°	18°	22°	24°	28°	32°C
Potato dextrose agar	10	5	0	0	2·4	3·9	6·1	7·8	8·5	8·5	8·3
Oat agar	10	5	0	0	3·6	5·3	6·7	7·9	8·5	8·5	7·9

Aeration and Desiccation.—Some tests were carried out to determine the effect of aeration and desiccation on the viability of the conidia of *Fusarium culmorum.* Heavy suspensions of the conidia were made in sterile water. After a time they settled to the bottom and formed a sediment layer. It was found that characteristic cultures could be obtained from this sediment when plated out, for over five months, when it was inconvenient to carry the test further. On examining the sediment no distinct evidence of chlamydospore formation could be found, but the outermost cells were disentigrating badly. It is possible that conidia under conditions of restricted oxygen may remain viable for a considerable period of time.

The effect of desiccation was determined in two ways. Conidia were dried on sterile cover slips and stored in sterile dry chambers. These were taken out and plated from time to time. They gave a good strong growth for over forty-nine days. A conidial suspension was mixed with sterile soil and dried rapidly to avoid contamination and germination. Small amounts of this mixture were plated out from time to time. Positive results were obtained for a period of two years.

From the above it will be seen that this fungus has a rather wide range of temperatures and is able to withstand, in the conidial form, various adverse conditions, which indicates the unusual adaptability of this type of organism, which is surely of as much pathological significance as the extreme specialization of other parasites.

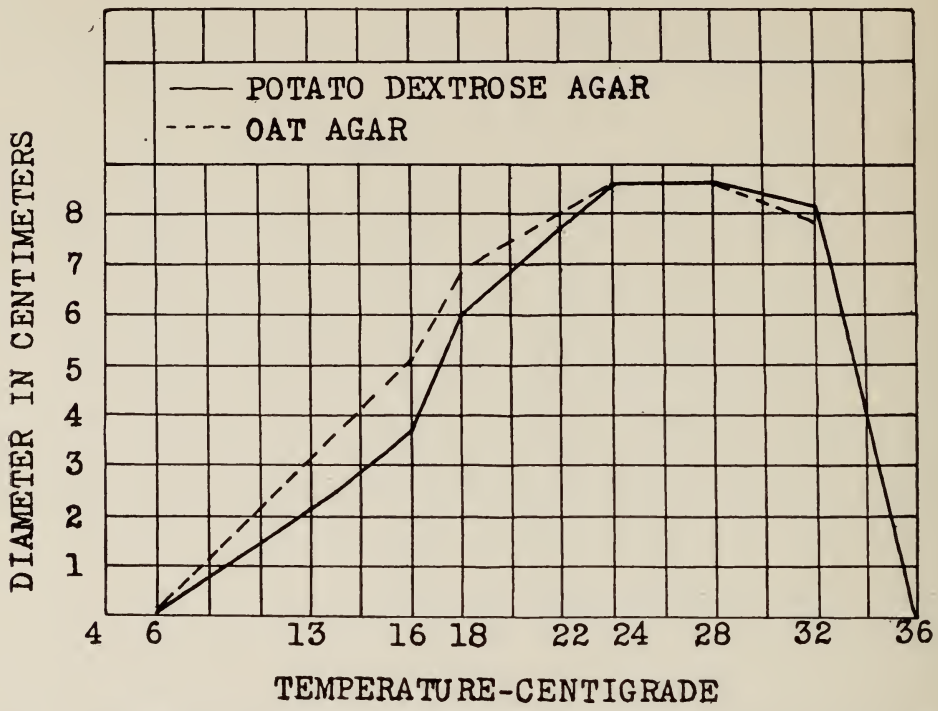

FIG. 7.—Graphs showing the vegetative development of *F. culmorum* at different temperatures.

PATHOGENICITY TEST

This test was run primarily to compare various cultures of *F. culmorum* obtained from widely separated localities and from different hosts. All cultures were grown from single spores before inoculations were attempted. One hundred seeds of each host were tested against each culture. Victory oats, Marquis wheat and Hannchen barley were used. Five-inch pots were used, with fifty seeds to a pot. Conidial suspensions for the inoculum were made with sterile water from potato dextrose agar slant cultures which were sporulating abundantly. In most cases the conidial suspension was heavy, with the larger bits of mycelium filtered out. The seeds were submerged in the suspension then picked out with forceps and planted. The suspension was not poured over the seed after sowing. The soil was not sterilized. Seven hundred kernels of each cereal grown were run as checks. These were interspersed at proper points when the experiment was arranged on the greenhouse bench. It is assumed that such a large number of checks would indicate any variation in the greenhouse temperature, as well as reveal natural infections. Watering was done frequently to maintain a favourable moisture content for the host plants. In taking the notes only the most severe phases of disease were recorded, namely, pre-emergence blight and seedling blight. The infection rate was obtained in a manner similar to that in use in the experiment on "Methods of Inoculation". See Table 2.

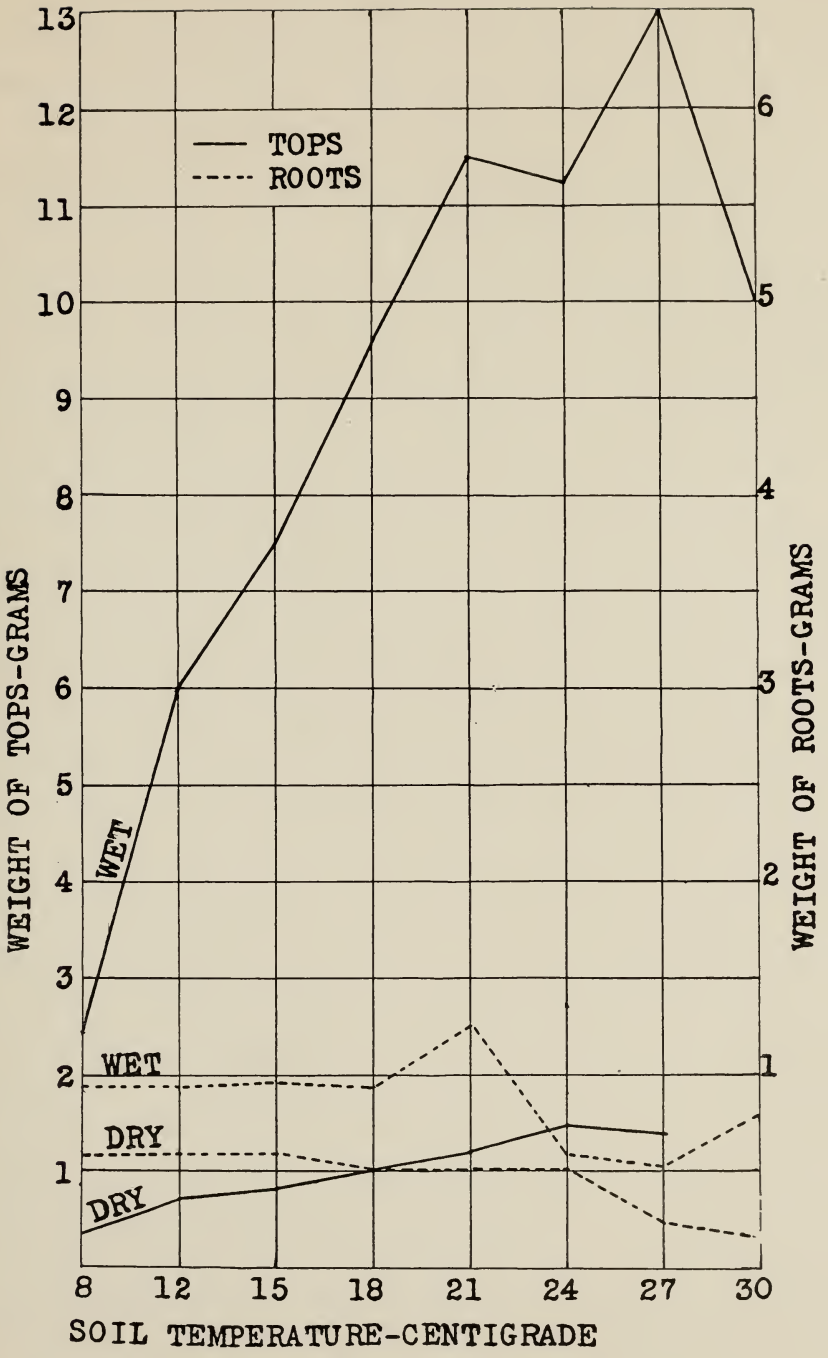

FIG. 8.—Graphs showing the average wet and dry weights of roots and tops of 40 plants taken from the checks grown at different soil temperatures with a soil moisture of 35 per cent.

TABLE 2.—PATHOGENICITY TESTS OF *Fusarium culmorum* CULTURES ISOLATED FROM VARIOUS HOSTS COLLECTED THROUGHOUT WESTERN CANADA.

Culture No.	Host part	Locality	Date isolated	Infection rate on		
				Oats	Wheat	Barley
				%	%	%
71	Oat foot	Swift Current	1923	79·5	41·7	79·2
83	Wheat head	Rosthern	1923	82·5	64·0	88·7
73	"	Saskatoon	1923	59·2	14·5	54·5
76	"	Brandon	1923	77·0	73·0	74·5
20	"	Tisdale	1922	94·2	70·7	94·2
106	"	Rosthern	1925	88·3	51·7	83·7
77	Wheat foot	Saskatoon	1924	90·2	21·7	86·2
100	"	Indian Head	1925	93·7	81·7	94·0
88	"	"	1925	87·2	70·7	87·5
98	"	Wolseley	1925	57·0	21·7	44·0
101	"	Indian Head	1925	82·7	49·7	76·5
64	"	Scott	1923	93·7	27·5	87·0
107	Barley foot	Saskatoon	1925	78·2	49·0	81·5
103	Corn stalk	Indian Head	1925	64·7	44·2	66·2
Average of all inoculations				80·5	48·8	78·4
Checks uninoculated				14·3	4·2	19·3

There was poor germination in both barley and oats, which accounts partly for the high infection rate in the checks of these two. The pathogenic nature of the cultures, however, is readily determined. The average of all experiments show that the greatest amount of disease is produced in oats and barley, regardless of the source of the culture. Wheat is generally least affected, but in this method of inoculation the wheat kernels no doubt retain much less of the suspension than either the oats or barley. Here also the stronger germination capacity of the wheat used is probably a factor also. Isolations from wheat heads (head blight or scab) are as severe in producing seedling blight as isolations from the culm or crown. It is also of interest to note that a culture which produces little disease manifests this alike on all three hosts. This test, although preliminary in nature, gives some idea of the distribution of the fungus in Western Canada, as well as its host range and relative pathogenicity.

LIFE-HISTORY IN RELATION TO THE PRODUCTION OF DISEASE

There are two main sources of inoculum from which the oat seedling may become infected: the soil and the seed. The fungus may live over winter in the crop debris, or in other organic material in the field. Isolations have been made readily from cereal stubble taken from the frozen soil early in the spring. It probably lives over under these conditions as dormant mycelium. It is quite possible that chlamydospores may survive the winter, but the writer has not proved this point. It has been shown, by Simmonds (34), that the fungus in culture will withstand exposures to low temperature without any ill effects. Under laboratory tests, it has been found to survive other adverse conditions. At any rate if the fungus is well established in the field, natural environment does not play a large rôle in control, and if the fungus mortality was high during the winter this would be offset by its rapid growth and dissemination, living erstwhile as a saprophyte.

Oats are not commonly affected with head blight, but there is sufficient opportunity in the field after cutting for the kernels to become contaminated, and the hulls particularly may bear the parasite in sufficient amount to result in an abundant primary infection. Consequently when the fungus is present to any great extent there are many chances for the plants to become infected. The degree and extent depends upon environmental factors, chiefly soil temperatures. If conditions are favourable the fungus develops rapidly, invading and

killing the basal parts of the plants as well as readily attacking parts which slough off. After thoroughly invading the tissue, it fruits, the condia are produced in abundance on the surface of the invaded part and are disseminated by splashing of rain, surface water, and the wind, so that from an initial source the spread may be both rapid and extensive. This development keeps up throughout the season, and the extent probably determines in a large measure the recurrence of the disease the following season.

THE RELATION OF ENVIRONMENT TO THE DEVELOPMENT OF THE HOST

Time would not permit a thorough study of the effect of environment upon the oat plant. Observations were made and notes taken throughout the soil temperature and moisture studies. The average height and leaf development of the plants are tabulated along with the general notes (tables 6, 7, 8). Also wet and dry weight determinations were made of the roots and tops of forty representative plants taken from the checks of each temperature in the 35 per cent and 20 per cent moisture series. The tops were separated from the root at the point of contact with the seed, so that the hulls went along with the roots. The drying was done in an oven running at 105° C. The dry weight was recorded when no further loss could be determined. It is unfortunate that wet and dry weights were not determined for the 50 per cent moisture series, as in general there was little difference to be noted between the 35 per cent and 20 per cent moisture series. In the 35 per cent moisture series the maximum wet weight and dry weight for the tops appeared to be at 27° and 24° respectively, with a continual increase in weight from the lower temperatures up to these points and a decline at the higher temperatures. The roots revealed maximum total and dry weights at the lower temperatures, with a general decrease towards the higher temperatures, except at 21°, where a sharp increase in total weight was noted and difficult to explain. In the 20 per cent moisture series the maxima of the total and dry weight of the tops was at 24°. The roots decreased in dry weight with the rise in soil temperature. In general there was a greater top development at the high temperatures, with a larger root development at the low temperatures. In the field during the cool period of spring there would be a vigorous root development, then after the plants became well established the warmer months would produce top growth. Such a development would seem exceedingly beneficial to the host from the standpoint of certain foot-rot or seedling blight diseases. (See tables 3 and 4 and figures 8 and 9.)

TABLE 3.—Average wet and dry weights in grams of roots and tops of 40 plants taken from the checks of the three tests in the 35% moisture series.

Temp. degrees Centigrade	Average wet weights in grams							
	Roots				Tops			
	1	2	3	Average	1	2	3	Average
8.....	0·938	0·803	1·104	0·948	2·220	2·084	3·015	2·439
12.....	0·896	0·860	1·034	0·930	1·788	6·611	9·811	6·070
15.....	1·040	0·844	1·050	0·978	1·820	9·430	11·311	7·520
18.....	1·192	0·901	0·661	0·918	2·880	11·099	14·821	9·600
21.....	2·524	0·562	0·743	1·277	1·800	13·897	19·035	11·577
24.....	0·960	0·508	0·527	0·665	2·680	12·471	18·508	11·219
27.....	0·636	0·630	0·514	0·594	1·060	15·492	20·432	13·328
30.....	1·080	0·734	0·574	0·796	2·680	10·589	17·714	10·327

Average dry weights in grams

Temp. degrees Centigrade	Average wet weights in grams							
	Roots				Tops			
	1	2	3	Average	1	2	3	Average
8	0·700	0·631	0·589	0·640	0·344	0·452	0·367	0·387
12	0·680	0·702	0·662	0·681	0·204	0·922	0·980	0·702
15	0·760	0·497	0·694	0·650	0·324	1·144	1·101	0·856
18	0·628	0·566	0·468	0·554	0·308	1·421	1·465	1·064
21	0·720	0·443	0·564	0·575	0·216	1·670	1·860	1·248
24	0·680	0·453	0·420	0·517	0·440	2·077	2·148	1·555
27	0·133	0·510	0·441	0·361	0·208	2·087	2·180	1·491
30	.....	0·112	0·469	0·290	.....	.....	.....	.....

Table 4.—Average wet and dry weights in grams of roots and tops of 40 plants taken from the check of the three tests in the 20% moisture series.

8	0·680	0·969	1·362	1·003	1·876	4·023	2·280	2·726
12	0·840	0·890	1·504	1·078	2·760	5·512	4·023	4·074
15	0·600	0·772	1·075	0·815	2·400	8·481	4·748	5·209
18	0·600	0·712	1·006	0·772	4·640	10·301	7·510	7·483
21	0·640	0·796	1·103	0·846	6·640	11·805	9·028	9·157
24	0·600	0·548	0·620	0·589	5·400	12·168	10·681	9·416
27	0·640	0·529	0·678	0·612	8·240	9·832	8·638	8·903
30	0·640	0·446	0·628	0·571	7·200	8·268	9·039	8·169

Average dry weights in grams

8	0·640	0·683	0·637	0·653	0·240	0·511	0·301	0·350
12	0·760	0·737	0·999	0·832	0·280	0·728	0·511	0·506
15	0·560	0·664	0·800	0·674	0·400	1·082	0·676	0·719
18	0·560	0·595	0·717	0·624	0·520	1·201	0·860	0·860
21	0·560	0·668	0·794	0·674	0·680	1·419	1·113	1·070
24	0·560	0·489	0·500	0·516	0·520	1·581	1·556	1·219
27	0·600	0·451	0·538	0·529	0·840	1·323	0·918	1·027
30	0·560	0·388	0·486	0·478	0·760	1·948	1·179	0·995

RELATION OF ENVIRONMENT TO THE DEVELOPMENT OF THE DISEASE

GREENHOUSE EXPERIMENTS

Experiment 1. Methods of Inoculation.—The primary object of this test was to determine the relative merits of some of the methods of inoculation which have been used in this type of study. The most common way has been to use a conidial suspension in which the seed are dipped before sowing, or which is poured over the seed at the time of sowing. This method is used in the tests on soil temperature and moisture relations. Cultures on grain mashes of different mixtures have been employed for inoculation purposes with fungi of this type. It is believed that when whole grain mashes are used there is a possibility of introducing certain toxic substances which may have a deleterious effect on the host. In an effort to avoid this a mash of ground oat hulls was tried out. The oat hulls are obtained from flour mills and contain apparently just enough meal to assist in the growth of the fungus. *Fusarium culmorum* grew rapidly and vigorously on this medium. Such a culture is readily broken up and can be used to advantage in greenhouse and field inoculations. It has given results as consistently as the suspension method, and is easier to apply. In this test the

method of application and the age of the cultures are the features given particular attention. A suspension method was tried but it was modified in that the seed after being dipped were rapidly dried, the conidia adhering to the grain. The advantage of this modification is that the seeds are dry and could if necessary be run through a drill, which would facilitate the inoculation of large field plots.

As this is an introductory experiment for others which follow, details of procedure and explanations thereof will be given. These tests were carried out in the greenhouses at the University of Saskatchewan during the winter of 1926-27. The greenhouse temperature would average between 20° and 24° C. with the usual variations.

Seed.—Banner oats obtained from the Field Husbandry Department, University of Saskatchewan, were used in this test. These were hand picked to avoid small or discoloured grains. They were not surface sterilized.

Pots.—Ordinary five-inch greenhouse pots were used and in each series they were arranged to equalize possible temperature variations. All pots were carefully washed between each change of soil.

Soil.—The soil was obtained from arable land and was of a clay loam type. It was mixed with river sand in the proportions of five to one. It was not sterilized. In previous tests such soil gave very few, if any, natural infections. Also unsterilized soil gave more uniform moisture distribution, especially when watered from the top. In any test where natural infection might interfere with the results care was taken in determining the amount of disease, and platings were made from typical as well as suspicious lesions to assure as near as possible a correct interpretation.

Inoculum.—Except where stated otherwise, oat hull mash cultures one month old were used. The cultures were broken up and mixed, then applied at the rate of approximately 7 grams to a pot except where the inoculum was mixed through the soil, when the amount was doubled. This amount has been found sufficient to give good results. The conidial suspension was made from oat hull mash cultures, and in application modified as stated above.

Data.—Notes were taken on the pre-emergence and seedling blight as soon as possible after complete emergence. After a period of at least three weeks the seedlings were harvested and the severity of the basal lesions recorded. In order to give the results on a percentage basis it was necessary to rate the different degrees of disease according to its significance, therefore pre-emergence blight is rated 4, seedling blight 3, severe and slight basal lesions 2 and 1 respectively. Lesions on the mesocotyl and coleoptile are designated as basal lesions. Thus the total infection rate for the first lot of this test may be determined as follows:—

Pre-emergence blight	110,	numerical rate	4,	equals	440
Seedling blight	6,	"	" 3,	"	18
Severe basal lesions	131,	"	" 2,	"	262
Slight basal lesions	48,	"	" 1,	"	48
			Total	-	768

according to the formula—

$$\frac{\text{Total number of numerical ratings x 100}}{\text{Total number of seed inoculated X maximum disease rate (4)}}$$

as—

$$\frac{768 \text{ X } 100}{400 \text{ X } 4} \text{ equals 48 per cent infection rate.}$$

66195—3½

In many cases, as in checks, the non-emergence may be due to lack of vigour, which is generally denoted as poor or weak germination. In some trials, as in the soil temperature and moisture tests, every kernel is accounted for, and a distinction is made between non-emergence or pre-emergence blight and failure to germinate due to lack of vigour. In most cases, however, it was not convenient to make this distinction, and so poor germination comes under non-emergence or pre-emergence blight, and is rated as disease. This, however, should not affect the disease index when similar groups of inoculated and check plants are compared.

The infection rates for all of the other cases were determined in a similar manner. The results are tabulated in table 5.

TABLE 5.—Results of various methods of inoculating oats with *Fusarium culmorum*.

Method	Number of seed	Emergence	Seedling blight	Basal lesions		Infection rate
				Severe	Slight	
						%
Inoculum placed at seed level	400	290	6	131	48	48
Mixed through soil	400	236	4	81	16	53·1
Mixed with sand at seed level	400	249	6	97	25	52·6
Placed 1 inch below seed level	400	343	1	50	22	22·0
Placed 2 inches above seed level	400	345	4	45	32	22·1
At seed level pot set in ½-inch water	400	293	10	27	18	33·1
Seed dipped in suspension then dried	400	295	4	80	54	43·7
Inoculum 7 days old placed at seed level	200	133	12	24	55	50·8
26 days old placed at seed level	400	157	2	88	10	46·7
Inoculum 8 months old placed at seed level	400	288	6	56	55	39·5

It was found that if the inoculum was placed at seed level, mixed with sand at seed level or mixed through the soil, the results were approximately the same. When placed one inch below seed level, or two inches above, the infection was less severe. When the inoculum is placed at seed level the fungus, in the case of oats, becomes established upon the hulls and is able to attack the first new tissues to appear. Inoculum either seven days or eight months old would produce the disease with a tendency favouring the younger culture. It is believed that a one-month-old culture strikes a fair average of what is desired.

The modified suspension method gave results comparable to the regular suspension or the oat hull method. It has the advantage that the seeds are dry and may be sown in large lots with a drill. This later method deserves further experimentation.

When a bran mash inoculum of the same fungus was used and placed against the wheat or oat kernels, the amount of disease was greatly increased, but as there is a tendency for such mash to become soggy and contaminated with bacteria, toxic substances may be produced. There is a possibility that the inoculum material whether a wheat product or an oat product may have some particular influence on the host.

For the present time the oat hull mash appears to give the most consistent results, and it is convenient to use, both in the field and greenhouse.

The Influence of Soil Temperature and Moisture.—The following experiments were carried out at the University of Wisconsin. The significance of environmental factors in diseases of the type under consideration here is very apparent, so these studies were conducted as thoroughly as possible.

A description of the experimental methods and equipment follows:—

Temperature.—Eight constant soil temperatures were obtained by the use of the Wisconsin soil temperature tanks as described by Jones (19). The temperatures employed were 8, 12, 15, 18, 21, 24, 27 and 30 degrees centigrade. For the 50 per cent soil moisture series the 8 degree tank had to be omitted.

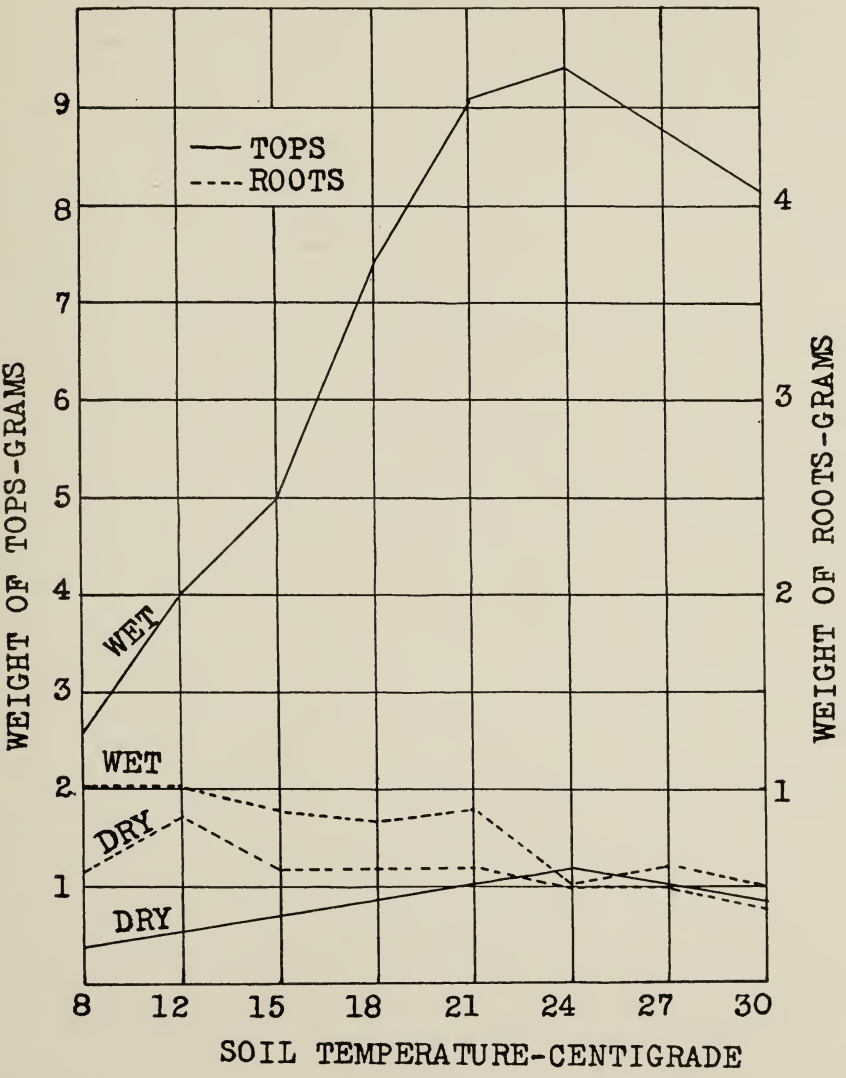

Fig. 9.—Graphs showing the average wet and dry weights of roots and tops of 40 plants taken from the checks grown at different soil temperatures with a soil moisture of 20 per cent.

Soil Moisture.—The moisture was determined on the basis of the moisture holding capacity of the soil. Three moistures, 50, 35 and 20 per cent, were used. In each series the desired moisture was calculated for each can, the cans were then made up to the proper weight and water added at regular intervals to keep them at the desired weight.

Soil.—The soil, except in the case of the 50 per cent moisture series which contained somewhat more sand, was of a uniform silt to sandy loam. It was sterilized for from four to five hours at approximately fifteen pounds pressure, then piled on a clean floor and allowed to temper for at least over night. Just before filling the cans, samples were taken to determine the amount of moisture present. The cans were filled to about seed level, then an inverted small flower-pot with a glass tube attached, constituting a sub-irrigation apparatus, was placed firmly in the centre of the can at the seed level. The seeds were planted around this pot and covered with a definite amount of soil so that the seeding level was approximately the same for all cans. A thin layer of white sand was added as a mulch.

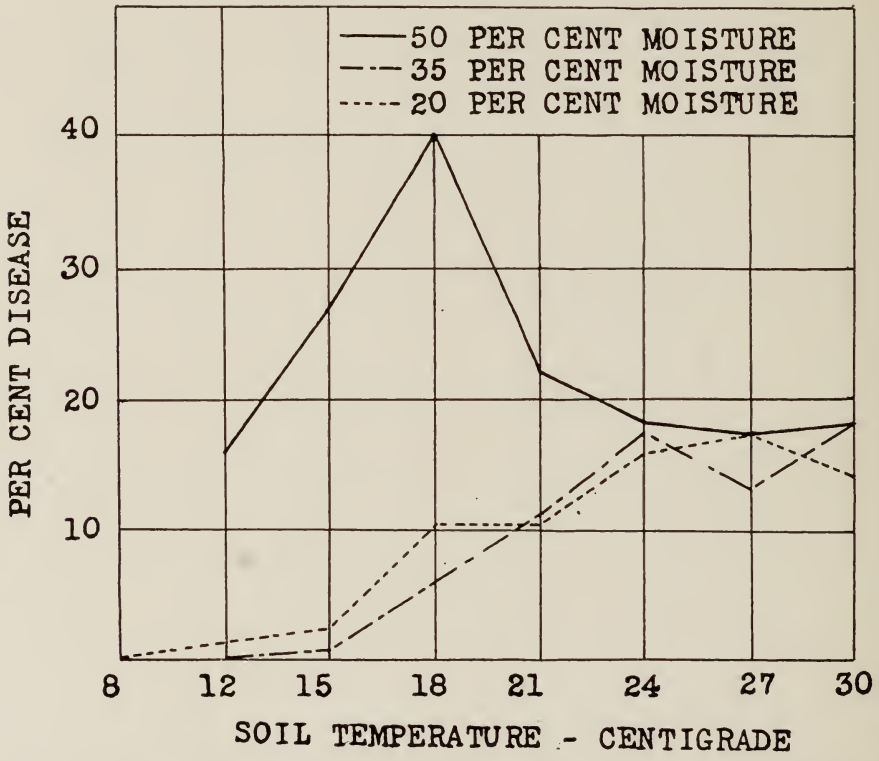

Fig. 10.—Graphs showing the effect of soil temperature and moisture on the development of disease.

Cans.—Metal water tight cans, 6 inches in diameter and 9½ inches deep, were used in all the tests. They were placed in the tanks so that the water level corresponded to the soil level.

Seed.—Wisconsin grown Victory oats, obtained from the Agronomy Department, were used in all the tests. They were surface sterilized by first washing in 80 per cent alcohol, submerged in bichloride of mercury solution (1:1000) for ten minutes, and finally washed three times in sterile water.

After the final wash the checks were planted and 20 cubic centimeters of sterile water poured over them. The seeds to be inoculated were submerged in the inoculum, then planted, and 20 cc. of the inoculum poured over them. The seeds were tested for germination and kernels plated out for the detection of possible internally borne fungi, before using for the experiments.

Inoculum.—The inoculum was made from two to three weeks old cultures on potato dextrose agar slants. The conidia were washed off in sterile water, and diluted to a suspension having from 100,000 to 130,000 conidia per cubic centimeter.

Experiment 2.—To determine the development of disease at 50 per cent of the moisture holding capacity of the soil, using seven temperatures from 12° to 30°C. Four cans were used in each temperature tank, two for checks and two inoculated; 30 seeds were sown in each can. Three series were run, so that a total of 180 kernels for checks and 180 inoculated comprised the experiment. The seedlings were allowed to develop for four weeks, when notes were taken for seedling blight, total emergence, height and leaf development. The plants were then harvested and notes taken for emergence blight, as well as for manifestations of severe and slight lesions on the mesocotyl region. The total infection rate was summarized in a similar manner as in experiment 1, taking into account seedling blight, severe and slight lesions, which were given the rates of 3, 2 and 1 respectively.

Sufficient lesions were plated to assure that they were not caused by a foreign pathogen, and all suspicious lesions occurring on the check plants were plated for the determination of the cause. The results of the experiment are given in table 6.

Table 6.—The effect of soil temperature and moisture upon the development of seedling blight of Victory oats. The soil was maintained at 50 per cent of the moisture holding capacity with temperatures ranging from 12° to 30°C.

Soil temperature	Air temperature	Number seed sown	Total emergence	Germination	Seedling blight	Emergence blight	Mesocotyl lesions		Infection	Average height in inches	Leaf stage
							Severe	Slight			
									per cent		
		180 check ..	165	165	.....	.....	.....	.....	.....	11	3
12°.....	16	180 inoc.....	167	169	5	2	30	4	15·7	11	3
		180 check...	149	149	.....	.....	.....	.....	.....	14	4
15°.....	20	180 inoc.....	160	160	5	4	53	13	27·0	14	4
		180 check...	166	166	.....	.....	.....	.....	.....	18	4
18°.....	20	180 inoc.....	159	163	7	4	81	24	40·5	18	4
		180 check...	165	165	.....	.....	.....	.....	.....	16	4+
21°.....	20	180 inoc.....	143	143	2	.....	57	7	23·5	16	4+
		180 check...	144	144	.....	.....	.....	.....	.....	18	5
24°.....	20	180 inoc.....	160	161	7	1	32	13	18·7	18	5
		180 check...	156	156	.....	.....	.....	.....	.....	14	5
27°.....	20	180 inoc.....	158	158	8	.....	32	7	17·5	14	5
		180 check...	154	154	.....	.....	.....	.....	.....	12	4+
30°.....	20	180 inoc.....	153	155	10	2	29	6	18·5	12	4+

Experiment 3.—The development of disease at 35 per cent of the moisture holding capacity of the soil, using eight temperatures. As in the previous experiment a total of 360 seeds were sown in three series. Notes were taken in the same manner as for Experiment 2. Results are given in table 7. (See figures 11 and 12).

TABLE 7.—The effect of soil temperature and moisture upon the development of seedling blight of Victory oats. The soil was maintained at 35 per cent of the moisture holding capacity with temperatures ranging from 8° to 30°C.

Soil temperature	Air temperature	Number seed sown	Time for emergence (days)	Total emergence	Germination	Seedling blight	Emergence blight	Mesocotyl lesions		Infection rate	Average height in inches	Leaf stage
								Severe	Slight			
										per cent		
		180 check...	14	169	169	.....	.....	.....	.....	.....	4	1
8°.....	18–20	180 inoc....	14	171	171	.....	.....	.....	.....	.....	4	1
		180 check...	12	171	171	.....	.....	.....	.....	.....	6	2+
12°.....	18–20	180 inoc.....	12	160	160	.....	.....	.....	.....	.....	6	2+
		180 check...	10	145	145	.....	.....	.....	.....	.....	6*	3
15°.....	18–20	180 inoc.....	10	154	154	1	.....	.....	.....	0·5	6*	3
		180 check...	8	153	153	.....	.....	.....	.....	.....	8	3+
18°.....	18–20	180 inoc.....	8	156	156	3	.....	10	3	5·9	8	3+
		180 check...	7	139	139	.....	.....	.....	.....	.....	8	3+
21°.....	18–20	180 inoc.....	7	136	139	3	3	24	2	12·5	8	3+
		180 check...	6	133	133	.....	.....	.....	.....	.....	8	3–4
24°.....	18–20	180 inoc.....	6	130	130	3	.....	33	1	17·7	8	3–4
		180 check...	5	128	128	.....	.....	.....	.....	.....	9	4
27°.....	18–20	180 inoc.....	5	122	122	.....	.....	37	.....	13·7	9	4
		180 check...	5	111	111	.....	.....	.....	.....	.....	9	4
30°.....	18–20	180 inoc....	5	104	104	3	.....	42	8	18·7	9	4

EXPERIMENT 4.—The development of disease at 20 per cent of the moisture holding capacity of the soil, using eight temperatures. The same number of seed and the same methods were used as in the previous experiments. Results are given in table 8.

FIG. 11.—Influence of soil temperature and moisture upon seedling blight of oats. Ten representative plants taken from the checks of the 35 per cent soil moisture experiment. A more vigorous root development is evident at the lower soil temperatures, with an increase in top growth at the higher temperatures. The mesocotyl region is more elongated and somewhat weaker in appearance at the higher temperatures, particularly is this noticeable at 30 degrees where occasionally the mesocotyl region is somewhat discoloured.

TABLE 8.—The effect of soil temperature and moisture upon the development of seedling blight of Victory oats. The soil was was maintained at 20 per cent of the moisture holding capacity with temperatures ranging from 8° to 30°C.

Soil temperature	Air temperature	Number seed sown	Time for emergence (days)	Total emergence	Germination	Seedling blight	Emergence blight	Mesocotyl lesions		Infection rate	Average height in inches	Leaf stage
								Severe	Slight			
										per cent		
		180 check	17	132	132						3	1
8°	18–20	180 inoc	17	114	114						3	1
		180 check	10	158	153						4	2
12°	18–20	180 inoc	10	117	120		3	1		2·0	4	2
		180 check	8	150	150						4·5	2+
15°	18–20	180 inoc	8	120	123		3	3	3	3·3	4·5	2+
		180 check	7	150	150						5	3+
18°	18–20	180 inoc	7	124	124	5		19	3	10·3	5	3+
		180 check	9	144	144						6	3+
21°	18–20	180 inoc	9	129	129	3		24	3	11	6	3+
		180 check	6	134	134						7	4
24°	18–20	180 inoc	6	119	120		1	36	11	15·9	7	4
		180 check	7	126	126						7	4
27°	18–20	180 inoc	7	129	133	3	4	31	9	17	7	4
		180 check	6	89	89						7·5	4
30°	18–20	180 inoc	6	97	101	2	4	28	4	11·4	7·5	4

In the 35 per cent and 20 per cent soil moisture tests there was an increase in disease development at the higher soil temperatures with a decrease to an insignificant amount at the lower temperatures. It was evident here that the influence of temperature on the fungus was an important factor, as the increase in disease compares favourably with the development of the fungus in artificial

FIG. 12.—Influence of soil temperature and moisture upon seedling blight of oats. Ten representative plants taken from those inoculated and which were exposed to various soil temperatures in the 35 per cent soil moisture experiment. In comparison with Figure 11, the general development of the plants is seen to be the same. Plants showing disease, as mesocotyl lesions, have been separated from the healthy ones. An increase in the amount of disease is particularly noted from 24° upward. The hardy seedlings and absence of disease, at the three lowest temperatures, is very evident.

cultures. (See fig. 7.) In the 50 per cent moisture such a regular increase in disease development was not obtained, but instead the optimum shifted towards the lower temperatures; at the same time, however, a significant amount of disease appeared at the higher temperatures (fig. 10). From these tests it seems that an increase in temperature along with an increase in moisture provides the most favourable condition for the development of the disease. The increase in the amount of disease with an increase in temperature may be explained on the basis of a direct influence of temperature upon the pathogen. The influence of moisture, however, is difficult to explain. It may have had a direct influence on the fungus or a detrimental effect upon the host, making it more susceptible. The relationship between the pathogen and host is probably one of more delicate balance than is commonly supposed, and such a balance may be very sensitive to environmental factors other than moisture and temperature directly. The small amount of diseases at the low temperatures, regardless of moisture, may be considered of significance when it is remembered that the seedling stage is a critical period in the growth of a cereal plant and the low soil temperatures of early spring would encourage a vigorous root development (fig. 11), at the same time retarding the progress of the pathogen. The evidence, therefore, from these tests would tend to encourage the practice of sowing oats on the earliest possible date.

Experiment 5. Depth of Seeding Test.—An endeavour was made to determine the effect of the depth of seeding when the plants were inoculated. The same general method of procedure and note taking were used as explained in experiment 1. The inoculum was made from a one-month-old culture of the fungus on oat hull mash, used at the ordinary rate, and applied at seed level. The soil was not sterilized and it is assumed that the checks indicate any natural infections. The results are given in table 9.

Table 9.—Results of tests to determine the effect of the depth of seeding on seedling blight produced by inoculations as well as natural infections.

Treatment	Depth	Seed	Emergence	Seedling blight	Basal lesions		Infection rate
					Severe	Slight	
							per cent
Check	1 inch	300	252		10	2	17·8
Inoc	1 "	300	113	16	17	6	69·8
Check	3 "	300	281		11	3	8·4
Inoc	3 "	300	85	5	21	6	76·9
Check	6 "	300	145	6	23	6	57·5
Inoc	6 "	300	72	4	25	3	81·4

In this test it was difficult to keep the soil moisture uniform, and in this respect the one-inch lot was at a disadvantage. It was determined, however, that these seedlings emerged a full two days before the three-inch group, whereas the deeper-sown seedlings were too irregular to obtain an average date. They were slightly later than the three-inch lot. The earliness of emergence is a very important factor in the field. Neither the one-inch nor the six-inch depths could be recommended for field practice, because of the moisture relationship in the first case and delay in the second. It appears that approximately three inches, but not greater, would be the most satisfactory. When the average emergence in the checks is considered this set is found to be the best. There is greater non-emergence under inoculations in the two deep-seeded lots, which shows the effect of delay in emergence when compared with one inch. This is, however, offset by the satisfactory emergence in the checks in the three-inch lot. It has been shown that the mesocotyl, which is the chief region of elongation

as the oat emerges, is very susceptible to attack. The elongation of this region is about proportional to the depth of seeding, hence the deeper seeding gives a greater exposure of the mesocotyl, as well as a delay in emergence. These two conditions which expose the seedling to infection can in a large measure be avoided. Any delay in the growth of the plants in the early stages is a handicap throughout its entire development. The long and thin mesocotyl is well shown in figure 13, as well as an abnormally elongated first internode in the seedling from a kernel sown at a depth of five inches; whereas in the seedling from a three-inch depth these regions are noticeably less elongated. In general the shallow-seeded grain produces a more compact and sturdy crown root system.

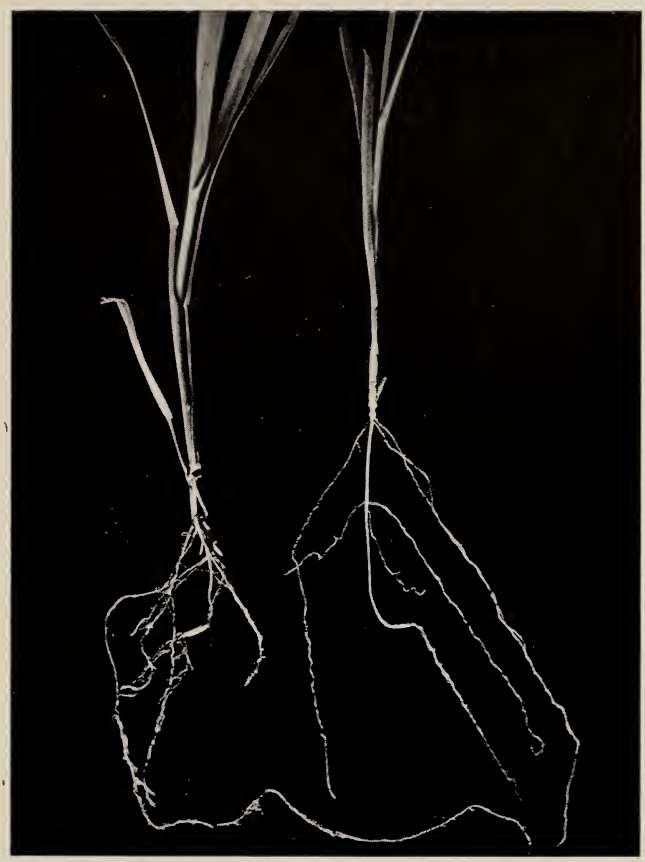

Fig. 13.—Showing the effects of deep seeding. The seedling on the right grew from an oat sown at a depth of five inches. Note the abnormally long mesocotyl and first internode. On the seedling on the left from a depth of three inches these regions are distinctly less elongated, more sturdy and in general the seedling is stronger. It has the better root system.

Experiment 6. Types of Soil.—A preliminary test was run to roughly determine the effect of various soil types. Large glazed stone crocks, 7 by 10, were used in this test. Victory oats, seeded fifty to a crock, were used, sown three inches deep. One set was of pure river sand, one of field soil and one of half sand and half soil. The soil or sand was not sterilized. Fourteen grams of inoculum was added at seed level. The results are given in table 10.

TABLE 10.—Results of tests to determine the effect of soil type upon the development of seedling blight.

Type	Treatment	No. seed	Emergence	Seedling blight	Infection rate
					per cent
	Check	200	171		14
Sand	Inoc.	200	128	26	45·7
	Check	200	152		24
Sand and soil	Inoc.	200	144	15	33·6
	Check	200	166		18·2
Soil	Inoc.	200	131	11	38·6

It is believed by some that this type of disease is most common in sandy soils because of the abundant aeration. In this test it was noted that the most disease appeared in the sand, when considering either the seedling blight or total infection rate. No seedling blight occurred in the checks. The best emergence for the checks was shown in the sand, followed in soil, and the emergence in the inoculated series reveals sand the poorest and soil next. In each case the half and half set was irregular. There appears to be some influence here which would indicate that soil type has an effect on the production of disease; this is probably linked with aeration. The sand clearly shows a high rate infection. There is not sufficient difference between the other two to suggest the attributing cause or causes.

FIELD EXPERIMENTS

EXPERIMENT 7. DATES OF SEEDING.—Plots of three rod rows each in duplicate were sown on three different dates at Indian Head. For each date four plots were sown, two inoculated and two to serve as checks. One hundred seeds were sown in each row. Oat hull mash inoculum was used at the rate of 45 grams per row. The plots were sown on the following dates,—May 6, May 24 and June 12. Emergence and seedling blight notes were taken at the proper time. At about flowering time the centre row from a check and an inoculated plot was taken out and examined for basal lesions. Thus only one hundred plants from each plot were examined for the lesion records. The total infection rate was obtained after the same manner as used in the greenhouse work. The results are given in table 11.

TABLE 11.—Results of tests to determine the influence of different dates of seeding on the development of seedling blight of oats.

Dates	Plots	Seed	Emergence	Seedling blight	Basal lesions		Infection rate
					Severe	Slight	
							per cent
	Check	600	573	2	6	7	9·5
May 6th	Inoc.	600	526	1	33	10	31·6
	Check	600	483		13	13	29·2
May 24	Inoc.	600	479	5	15	17	32·5
	Check	600	478		35	19	42·5
June 12	Inoc.	500	359	11	45	16	51·8

Low soil temperatures, averaging 12° to 15° C, prevailed until about the middle of June, so that there was an unusually low temperature range during the seedling stage of all sowings. There was abundant moisture. Such low soil temperatures would be unfavourable for the development of the disease, and may explain the low percentage of seedling blight. In general it is to be noted that the least amount of disease appeared in the first seeding, and the most in the late sown plots. The last seeding also showed less tillering. In appearance the first had by far the most vigorous plants. In considering the natural infections, as revealed by the checks, there is an increase in the second seeding over the first, and further increase in the third. In the inoculated there is not a great deal of difference between the first and second, but the third shows a distinct increase in amount of disease. Natural infections appear here to be a potent source of inoculation, and are greatly influenced in development by the environmental factors. The difference in the artificial inoculations is not as marked as one might suppose, judging from results obtained under controlled conditions, but it tends to demonstrate the difficulty of inoculating with this type of organism under field conditions. It is believed that it takes the fungus some time under these conditions to adjust itself, thus giving the seedling a period in which to get a start.

STUDIES ON CONTROL

There appears to be no direct and specific way in which to attack the foot-rot and seedling blight diseases, as regards control measures. Proper cultural methods, including rotations, the possibility of developing resistant varieties, and the use of chemical compounds for seed treatments, are suggested as methods to assist in the control of such diseases. A study has been made of the use of seed treatments for the control of seedling blight of oats caused by *Fusarium culmorum* and the results will be presented here, after which the general situation as it applies to this disease will be discussed.

Experiment 8. The Effect of Chemical Seed Treatments at Different Temperatures under Greenhouse Conditions.—Three constant soil temperatures were chosen—12°, 24° and 30° C., thus giving a low, optimum, and a high temperature for the development of the pathogen. The moisture was maintained at 50 per cent of the moisture holding capacity of the soil. The cans were prepared in the same manner as described for the experiments on soil temperature and moisture, except that the sub-irrigation apparatus was omitted. The inoculum consisted of a vigorously sporulating culture on oat hull mash. Three series were run to make a total of 150 kernels. Fifty kernels were planted in each can. The soil was sterilized. The seed was not surface sterilized. The checks show the success of the inoculaton. The treatments were as follows—Formalin 1-320, dipped for 10 minutes, then dried; copper carbonate dust 54 per cent, to coat the seed; uspulun 0·5 per cent solution, soaked for 30 minutes and dried. The results are given in table 12. (See fig. 14).

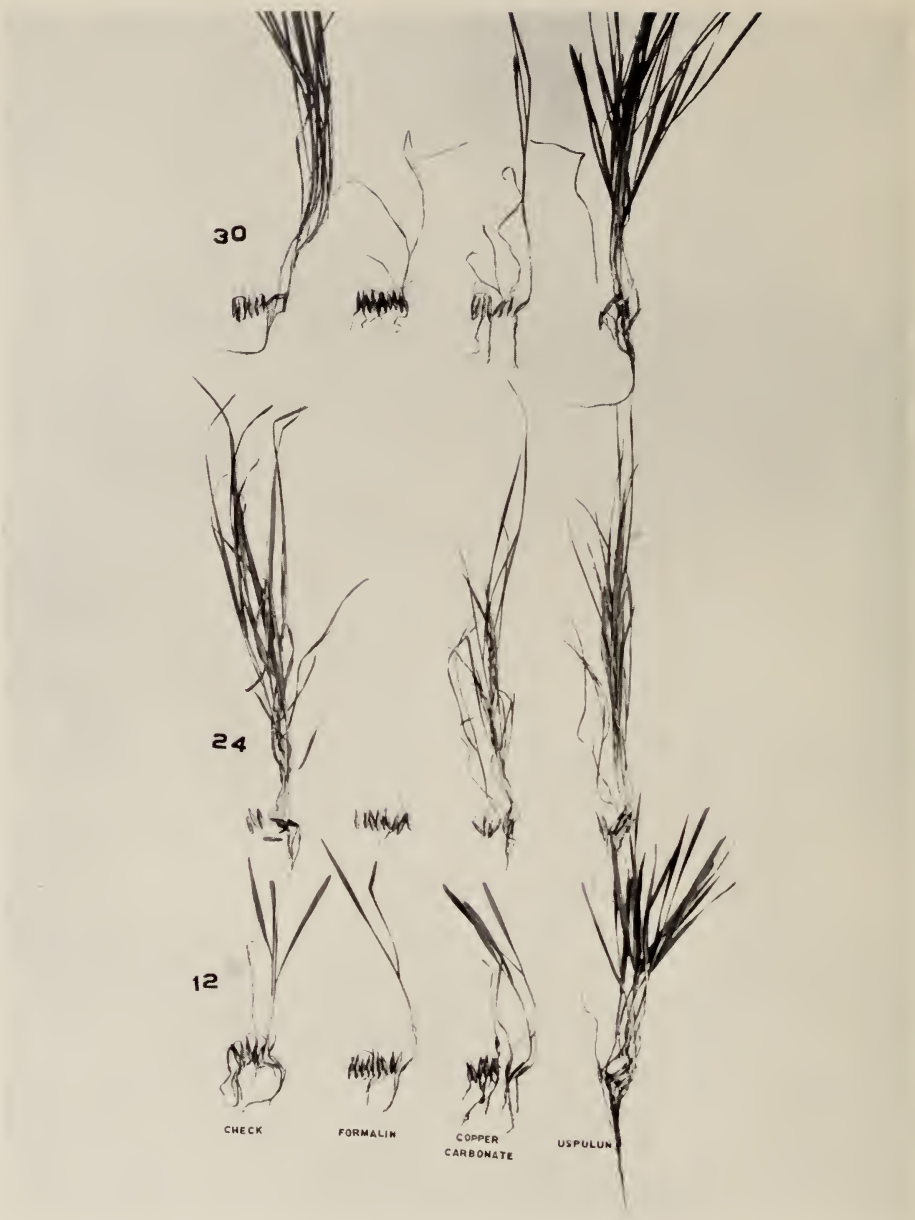

FIG. 14.—Showing the result of seed treatments at three soil temperatures—12°, 24° and 30° C. Each lot had been inoculated with *Fusarium culmorum*, the checks showing the severity of the disease. Temperature did not appear to have any definite influence. Formalin gave the poorest control, while uspulun was the best. Under these severe conditions copper carbonate gave only moderate protection.

Table 12.—Results of tests to determine the influence of soil temperatures on the effectiveness of chemical seed treatments in the control of the seedling blight of oats.

Temperature	Treatment	Number of seed	Emergence blight	Seedling blight	Basal lesions		Infection rate
					Severe	Slight	
							per cent
12 degrees	Check	150	101	9	7	1	91·0
	Formalin	150	109	2	.....	.....	76·3
	Copper carbonate	150	63	32	17	5	64·5
	Uspulun	150	.....	9	33	26	19·8
24 degrees	Check	150	71	8	15	2	56·6
	Formalin	150	112	5	.....	.....	77·1
	Copper carbonate	150	61	29	21	.....	62·1
	Uspulun	150	3	21	69	13	37·6
30 degrees	Check	150	86	13	19	.....	70·1
	Formalin	150	109	7	2	2	77·1
	Copper carbonate	150	33	32	37	5	51·1
	Uspulun	150	3	10	72	6	32·0

Experiment 9. Protective Influence of Certain Seed Treatments. —Some of the compounds recently placed upon the market for treating cereal seeds were tried out to see if they offer protection against artificial inoculation, as well as whether they might prevent natural infections.

A test was outlined so as to cover both of these features. One series was run without inoculation along with a series which was inoculated, all other conditions being the same. The soil was not sterilized so that there was an opportunity for natural infections. Five-inch pots were used for the test, fifty seed to each. Banner oats were used. A total of three hundred kernels were tested for each treatment, run in three series of one hundred each. Several sets of checks were run. All solutions were made up with distilled water. The following compounds and chemicals were tested:—

Dupont semesan 0·3 per cent solution; seed soaked 1 hour, then dried
Chlorophol 0·3 " " " " " " " "
Uspulun 0·3 " " " " " " " "
Germisan 0·3 " " " " " " " "
Tillantin 0·3 " " " " " " " "
Segetan dust
Urania dust
Dupont dust No. 12
" " " 49
" " " 46
" " " 57
Sulphur " (flowers)
Formaldehyde, 1-320 solution, seed dipped 5 minutes, drained, covered 15 minutes, then dried.

The grain was shaken up with the dusts then picked out to avoid sowing an excess of the chemical dust.

The results are given in table 13. (See fig. 15.)

TABLE 13.—Results of tests to determine the value of seed treatments in protecting oats from natural infections as well as from artificial inoculations.

Treatments	Soil without inoculation				Soil with inoculation		
	Number of seed	Emergence	Seedling blight	Infection rate	Emergence	Seedling blight	Infection rate
				per cent			per cent
Check	300	254	3	16·0	152	9	51·7
Semesan	300	298	3	1·4	273	11	11·5
Germisan	300	293	2	2·8	290	4	4·3
Uspulun	300	294	2	2·5	276	7	9·7
Tillantin	300	284	6	6·8	295	2	2·1
Check	300	250	8	18·6	169	13	46·9
Segetan	300	297	1	1·0	281	22	11·8
Urania	300	296	3	2·0	289	10	6·1
Dupont 12	300	298	.....	0·6	296	.....	1·3
Check	300	253	.....	15·7	171	18	47·5
Dupont 49	300	256	.....	14·6	175	32	83·0
Dupont 46	300	258	3	14·7	161	21	51·5
Dupont 57	300	275	4	9·3	226	21	29·9
Sulphur dust	300	233	4	26·3	121	17	63·9
Formalin	300	214	7	30·4	86	13	74·5
Check	300	259	4	15·0	120	11	62·7

EXPERIMENT 10. THE EFFECT OF CHEMICAL SEED TREATMENTS UNDER FIELD CONDITIONS.—Some of the common seed treatments were tested under field conditions at Indian Head. Plots of three rod rows were used, one hundred seed to a row. Two check plots were run, one without inoculation to determine the amount of natural infection, and one to determine the effect of inoculation. All plots except No. 1 were inoculated with approximately 45 grams of the oat hull mash inoculum, sprinkled in the row on the seed at the time of sowing. Victory oats were used in this test. The treatments were applied as in the greenhouse tests. Platings were made from all suspicious lesions. The fungus was readily recovered from plot 2. The results are given in table 14.

TABLE 14.—Results of chemical seed treatments under field conditions upon the development of seedling blight of oats.

Treatment	Emergence	Seedling blight	Basal lesions		Infection rate
			Severe	Slight	
					per cent
Check (1)	95·3	.....	4	9	8·9
Check (2)	72·6	1·3	28	3	43·1
Semesan	93·0	.....	30	11	24·7
Chlorophol	87·6	.....	16	10	24·2
Uspulun	85·0	.....	26	3	28·7
Germisan	84·6	.....	17	6	25·4
Tillantin	78·3	.....	10	5	27·9
Sulphur dust	69·3	.....	24	10	45·2
Copper carbonate dust	82·6	.....	18	12	29·4

EXPERIMENT 11. VARIETAL RESISTANCE.—Some of the leading oat varieties, as well as some varieties which have been used in stem rust resistance work, were tried out under controlled conditions to determine if there were any well-defined differences in resistance.

The general method of procedure was the same as with the previous greenhouse tests. Five-inch pots were used, fifty seeds in a pot. Three series were run to make a total of three hundred seeds in both the check and the inoculated. The soil was sterilized. Supplementary to this test two lots of Banner oats with

FIG. 15.—The effect of seed treatments. From left to right—Check, formalin, semesan dip and Dupont No. 12 dust. Fifty seed were sown in each case and all inoculated. (See Experiment 9.)

their hulls removed were run for comparison, and to determine the effect of the hulls upon relative susceptibility. The following varieties were tested, from the Field Husbandry Department, University of Saskatchewan: Banner 144, Gold Rain 111, Leader 143, Victory 145; from the Dominion Rust Research Laboratory, Winnipeg: Heigera rustproof selection, Joanette selection, Monarch selection, Richland, Minnesota 437, and Minnesota 439.

The results are given in table 15.

TABLE 15.—Results of tests made to determine varietal resistance against *Fusarium culmorum*.

Variety	Treatments	Number of seed	Emergence	Seedling blight	Basal lesions		Infection rate
					Severe	Slight	
							per cent
Banner	Check	300	273	2			9·5
	Inoc.	300	63	27	20	2	89·2
Gold Rain	Check	300	290				3·3
	Inoc.	300	62	23	21	14	89·7
Leader	Check	300	267				11·0
	Inoc.	300	72	27	35		88·5
Victory	Check	300	283				5·6
	Inoc.	300	63	32	15	6	90·0
Minnesota	Check	300	287				4·3
439	Inoc.	300	77	28	18	7	84·9
Minnesota	Check	300	270	2			15·0
437	Inoc.	300	70	46	21		91·6
Monarch	Check	300	278				7·3
	Inoc.	300	139	56	30	7	73·5
Heigera	Check	300	267				11·0
	Inoc.	300	83	22	19	4	81·3
Joanette	Check	300	265				11·6
	Inoc.	300	203	6	26	11	39·0
Richland	Check	300	277	1			7·9
	Inoc.	300	86	40	28	6	86·5
Banner minus hulls	Check	200	185				7·5
	Inoc.	200	101	28	45	28	49·8

In experiment 8 all of the checks show a significant amount of infection. The high infection in the 12° checks, as compared with the 24° checks, the writer believes to be due to the type of inoculum used. Although 24° is a favourable temperature for the development of the disease, the soil moisture content employed in this test would tend to shift the disease optimum towards the lower temperature. This, coupled with a retardation in rate of growth and the type of inoculum used, probably offset to some extent the influence of temperature, and explains the high pre-emergence blight at 12°. The formalin treatment did not show any control, in fact as in other experiments to be discussed later it appears to predispose the seedlings to blight. This predisposing influence, however was not affected by the temperatures as much as one might expect considering that the metabolism of the host, as shown by the rate of growth, is undoubtedly greatly influenced. Copper carbonate dust did not have any distinct effect. The influence of uspulun is noteworthy, showing splendid protection at the low temperature when compared with the amount of disease which appeared in the check. An appreciable amount of control was likewise obtained with this compound at the higher temperatures. This test demonstrates in a preliminary way at least that certain treatments are effective within a wide temperature range, whereas others are as distinctly ineffective.

In experiment 9 it is interesting to note, firstly, the reaction of the various treatments on the emergence of the seedling in plain soil, exposed as one might expect to natural infections. Judging from the checks it may be said that the germination was about normal and only a small amount of seedling blight occurred. Marked increase in germination as well as protection was shown by

the following treatments: Semesan, germisan, uspulun, tillantin, segetan, urania and Dupont dust No. 12. The remaining treatments did not offer any protection, and on the other hand formalin and sulphur dust appeared to hinder emergence and predispose the seedlings to the disease. In considering the comparable series which had been inoculated, it is noticeable that the checks show sufficient disease to denote that the inoculation was successful. It is likewise seen that those treatments mentioned above also gave noteworthy protection against subsequent inoculation with the fungus. The sulphur and formalin treatments reveal more disease than the checks. From this experiment it is evident that several of the seed treatments which are being used for the control of smut do, under controlled conditions, not only protect the seedling from infections by the fungus considered here, but protect it from presumably natural infections resulting in an increase in emergence over the untreated. In the field, of course, various factors interfere with such clear-cut results, but experiments are being carried out to determine the value of such treatments in practice.

In experiment 10 there was very little natural infection, judging from plot 1. Plot 2 showed much more disease than any of the others, except sulphur. Most of the treatments gave some control, which is in agreement with the greenhouse work. The data here, however, deal chiefly with the severity of the lesions, which is a possible source of error. It is believed that the comparison here is noteworthy. The season, as stated before, was not favourable for the development of the disease, yet plots 2 and 8 show clearly the effect of inoculation.

In experiment 11 it will be seen that all of the common varieties were susceptible. It is interesting to note, however, that of all those used the black varieties were the only ones to show any evidence of resistance; this was particularly true of Joanette. It is intended to follow this further, as it appears to be significant when one considers the very favourable disease conditions under which the test was carried out. At first it was thought that this resistance was due to more rapid growth and earlier emergence, but comparison with other varieties disproved this point. It is of interest to notice that Banner with the hulls removed showed considerably less disease than the ordinary seed; most of this difference appears to be due to the better emergence when the hulls are removed. It was noted that these seeds got an earlier start and apparently avoided considerable infection, perhaps from the fungus growing first in the dead oat hulls.

It will be seen from the above that seed treatments and development of resistant varieties show some promise in controlling these diseases. The problem, however, is very complex and while detail studies are being made it is well to keep in mind cultural methods, which the writer believes to be of considerable importance in controlling these diseases. It is a common practice to sow grain rather deep, often deeper than three inches. Observations show that such seedlings are usually subject to severe lesions. The excessive elongation of the mesocotyl predisposes the seedling to attack as pointed out in experiment 5. Deep seeding also retards emergence, and the possibilities of pre-emergence blight are greatly increased. Seeding beyond a depth of three inches should be avoided. The effect of high soil temperatures in increasing the disease is shown in experiments 2, 3 and 4. To overcome this, all spring grain except barley should be sown as early as possible to take advantage of the low soil temperatures. In fields where the disease has been severe it was noticed that where the tracks of the seeder wheels ran, the plants were more sturdy and vigorous, which presumably was associated with the packing of the soil and consequent improved moisture relations. In the Indian Head district there appears to be little doubt that proper packing after seeding will encourage strong seedling growth. This type of disease appears to be most severe on the summer-fallow crop, which may be associated with deep seeding which is possible on well-

cultivated land, or with warmer soil temperatures and greater aeration. It has been noticed that there is less disease where old straw stacks have been, and also where barnyard manure has been applied. This is probably associated with an increase in humus, imparting to the soil a more uniform moisture condition. The direct nutrient effect of barnyard manure when applied to prairie soil is never very marked under normal conditions, but under conditions of apparent foot-rot diseases, when the seedlings have difficulty in getting established, its effect is quite apparent. Grain, following crops which have been heavy users of moisture as sunflowers and corn, are usually more severely affected than when following another grain crop, but this rule does not always hold. Observations as the above are only indicative, as they refer to a complex situation in the field. In the case of seedling blight and foot-rot of oats caused by *Fusarium culmorum,* the writer believes the following recommendations can be made: Sow as early as possible. Do not sow deeper than three inches, and if possible pack after seeding. Packing after seeding may not be beneficial in some districts. This problem, however, can best be decided by the experienced farmers of the region concerned. The use of seed treatments, although promising, is still in the experimental stage as far as field practice is concerned.

SUMMARY

1. A seedling blight and foot-rot disease of oats caused by *Fusarium culmorum* is defined.
2. The hosts include all the cereals, but oats are probably most severely affected.
3. This type of disease appears to be common in Western Canada, the adjacent territory in the United States as well as the Pacific Coast States.
4. The losses due to the disease are difficult to determine, but under certain conditions they are probably very great.
5. The symptoms may be divided into pre-emergence blight, which is a blighting before the seedling appears above ground; seedling blight, which is a blight appearing shortly after the seedling emerges; and basal lesions, which includes the dark brown lesions on the coleoptile, mesocotyl, and roots of older seedlings and mature plants.
6. A description is given of the morphology of the mesocotyl and primary roots, showing the vascular system.
7. In single penetrations the germ-tube forms a small appressorium over a union of vertical cell walls; the walls are slightly swollen, which may assist in a clevage between them. It is believed that the most common form of penetration is when several germ-tubes unite to form a strand under which many penetrating hyphæ enter. These observations deal with the coleoptile and mesocotyl in their very early stages.
8. After penetration, invasion is very rapid in the cortex of the mesocotyl and coleoptile. In the crown region, root initials and tiller buds are attacked. The invasion is somewhat arrested at the endodermis.
9. The cortex of the root is readily invaded with some evidence of penetration through the root hairs.
10. There is a similarity between *Fusarium culmorum,* the casual organism, and the Fusarium stage of *Gibberella Saubinetii,* the former, however, invariably produces chlamydospores which is a distinguishing character.
11. *Fusarium culmorum* in cultures will develop over a wide range of temperatures from 4° to 32° C. The optimum lies in the vicinity of 24° to 28° C.

12. The fungus will withstand quite extreme desiccation. In one test where a conidial suspension was mixed with sterile soil, then dried, a characteristic growth was obtained after a period of two years.
13. Fourteen isolations from various localities and different hosts were found to be highly pathogenic on oats, wheat and barley.
14. In its life history the fungus is both parasitic and saprophytic. The initial infection comes from the soil or seed, pre-emergence blight, seedling blight and foot-rot follow. Sporulation is rapid as the organism develops saprophytically on dead plant fragments. It lives over the winter on the stubble and such debris, or is carried over on the seed.
15. The oat seedling develops a very strong root system at the lower temperatures, 12° to 15° C., while top growth is best at 24° to 28° C.
16. For inoculation purposes a conidial suspension or a culture on oat hull mash gave comparable results.
17. Very little disease develops on plants grown at low temperatures, 8° to 15° C; from 18° to 30° the progress of the disease is more rapid. This was true with soil moistures of 20 and 35 per cent of the moisture holding capacity of the soil; at 50 per cent moisture somewhat more disease was evident at the lower temperatures.
18. Deep seeding has a tendency to increase the disease; a depth of not more than 3 inches is recommended.
19. Sandy soils under experimental conditions showed slightly more disease than other types, the relationship may be one of aeration and moisture or more probably a combination of factors.
20. In the field, plots sown early in the season to take advantage of low soil temperatures are less diseased than later sown plots.
21. Certain seed treatments such as semesan, germisan, uspulun, tillantin, segetan, urania and Dupont dust No. 12 gave good control under greenhouse conditions. Formalin and sulphur did not control seedling blight.
22. Seed treatments in the field tests compared quite favourably with the greenhouse tests, although at present they are not recommended as a control measure for general practice.
23. Joanette, a variety of black oats, was the only one to give any indication of resistance.

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Explanation of Plates 1 and 2

Plate 1

All the photomicrographs were made with a Zeiss microscope. Fig. A was made with an oil immersion objective. Figs. B, C, D, E and F were made with the high dry objective.

Fig. A. Part of a cortical cell and root hair of Ligowo oat seedling containing a hyphal thread. The kernels were surface sterilized, then plated on potato dextrose agar. After germination they were inoculated, by means of an atomizer, with a conidial suspension of *F. culmorum*. The plates were kept at room temperature. After 2 days rootlets showing lesions were fixed and prepared for sectioning.

Fig. B. Early invasion of the cortical cells of the coleoptile of Banner oat. Longitudinal section.

Fig. C. A well-established invasion of the cortex of the coleoptile of Banner oat. Note the swellings of the hyphae in the endodermal region. Longitudinal section.

Fig. D. An invasion of the cortex adjacent to the stele of the mesocotyl of Banner oat. In several places the passage of the hyphae through the cell walls can be seen.

Fig. E. A longitudinal section of coleoptile of Banner oat showing part of the epidermis bearing callosities. Fixed 48 hours after inoculation. Inoculated at 18° C. Stained with safranin. A cell wall reaction brought out by the staining can be seen adjacent to the callosity.

Fig. F. A longitudinal section from the mesocotyl of Banner oat showing part of the epidermis. Some hyphae may be seen, as well as distinct penetration areas where the cell wall is altered or partly dissolved. Inoculated and incubated at 18° C. for 30 hours. Stained with safranin and Gentian violet.

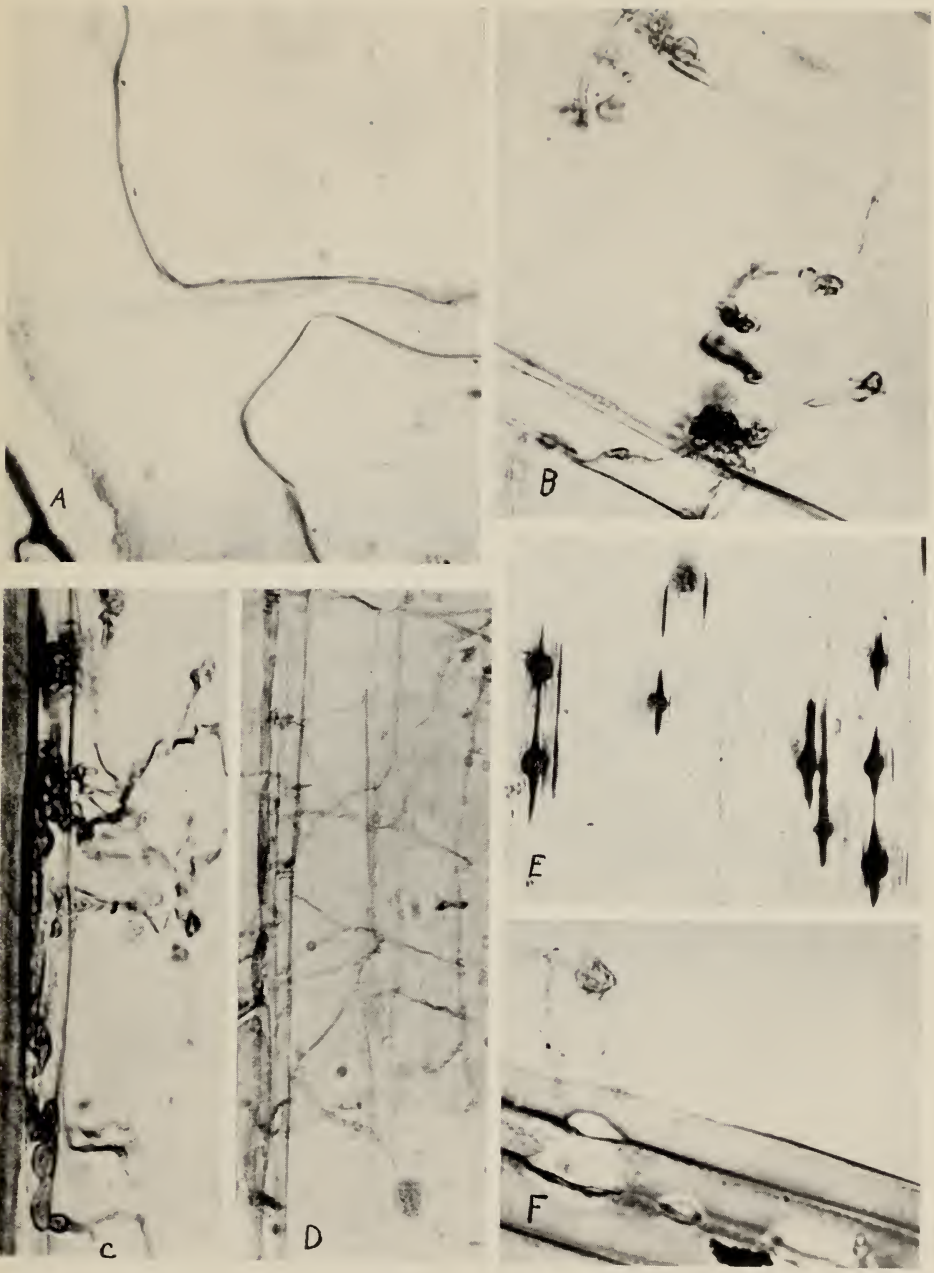

A
B
C
D
E
F

Plate 2

These photomicrographs were made with a Zeiss microscope using the high dry objective.

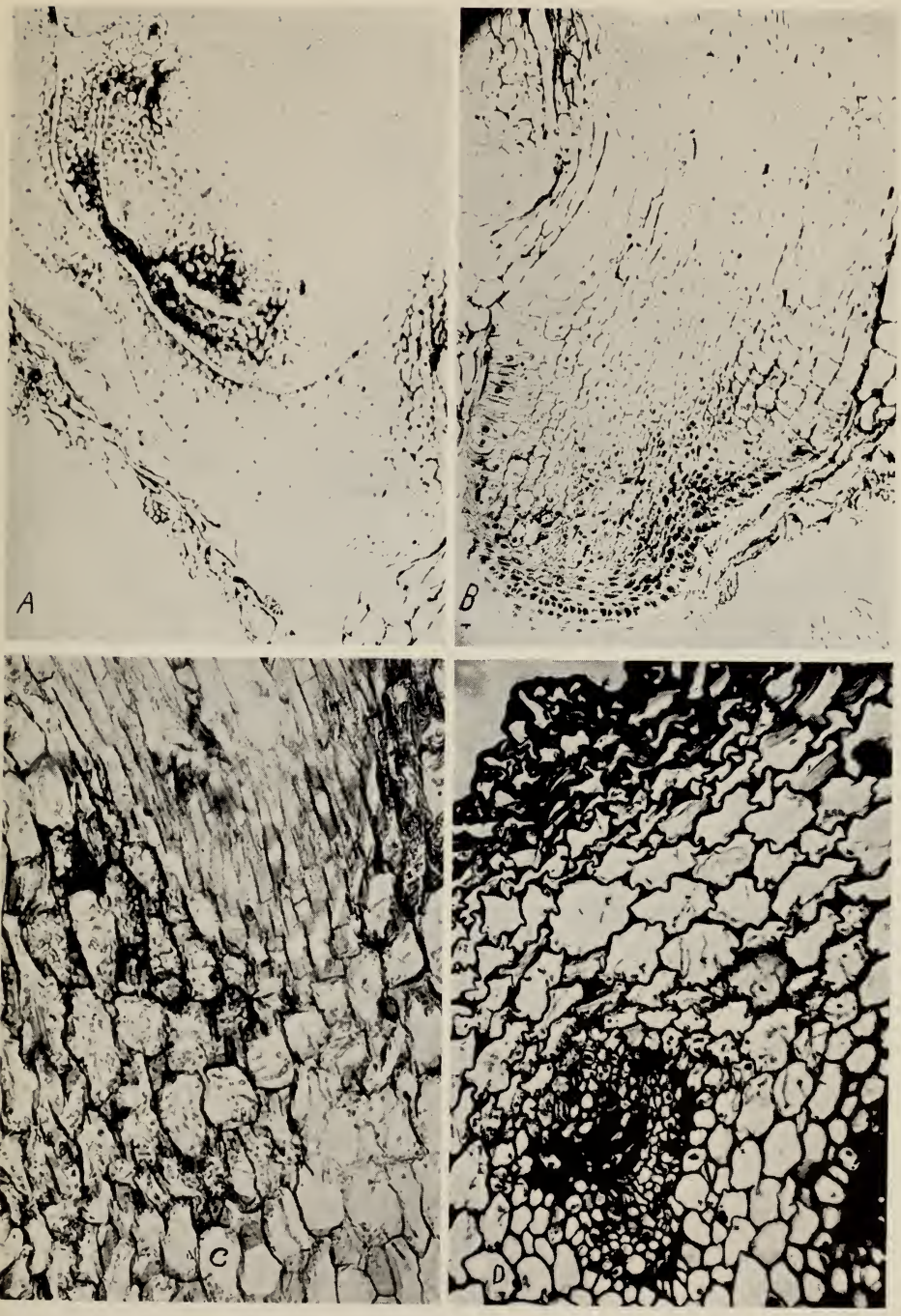
Fig. A. A transverse section at the crown of a seedling taken from the 24° C., inoculated series, of Experiment 3. The invasion is well established. A mass of mycelium may be noted between the broken down leaf sheath and the tiller bud. The disorganization of the cells of the bud is clearly shown. Stained with safranin and Gentian violet.

Fig. B. A transverse section in the same series as Fig. A. The early stages in the infection of a root initial. The cortical cells adjacent to the invaded coleoptile are disorganized and breaking down.

Fig. C. A transverse section in the same series as Fig. A, but showing a root initial the cortical cells of which are thoroughly invaded.

Fig. D. A transverse section of the mesocotyl of a seedling showing severe lesions. Taken from the 24° C., inoculated series of Experiment 4. The scutellum trace is shown. The mycelium is quite distinct between the scutellum trace, which is well invaded, and the stele. The latter is not invaded to any extent. Stained with safranin and Gentian violet.

PLATE II



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