

SNOW-MOLD ON TURF GRASSES

A thesis submitted to the Graduate School of
the University of Wisconsin in partial fulfill-
ment of the requirements for the degree of Doctor
of Philosophy.

by

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SNOW-MOLD ON TURF GRASSES

I. INTRODUCTION

The culture of grasses in turf on lawns and on golf courses has, in the last few years, become a problem of increasing complexity. The grass is grown under very intensive and artificial conditions. The demand for better and finer turf has been increasing. The plants are continually forced in their growth by additions of nitrogen fertilizers which stimulate a strong vegetative growth. The attempt is made to keep the plants in a vegetative condition throughout the year. With such intensive cultural practices, problems of disease become increasingly important. One of the serious problems that growers of fine turf have to deal with in certain sections of the country has been the killing of turf during the winter. Much of this winter-killing has been caused by poor drainage, drying out, and late freezes in the spring, after the grass has begun to grow. Another type of winter-killing has been that caused by disease. This disease is called snow-mold because of the time of its appearance and its association with drifts of snow.

This study of snow-mold has been supported by the United States Golf Association Green Section for the last four years. The purpose of the study was to determine the cause of the disease and work out the relation between the host and the parasite. It was also desired to find the climatic and soil condition which favored its development, the influences of cultural practices, and to work out some

means of control.

Snow-mold has been reported to be prevalent both in this country and in Europe. In Europe it occurs on winter grains and on lawns in Northern Germany, Denmark, Norway, Sweden and Russia. On this continent it is prevalent in the northern tier of states and in Canada. It is most important in Wisconsin, Minnesota, Michigan and Canada. It may occur with severity in other states of the same latitude but not as generally. In the states south of the northern tier it is frequently found in a few places but does not cause as much damage. It has been reported as far south as Washington, D. C. and this year was reported in Philadelphia.

Most of the damage to turf in this country occurs on putting greens on golf courses. It also occurs on fairways and lawns. When it occurs on putting greens it often kills the turf outright. In such cases the turf must be replaced. Where turf is available to resod injured greens it is very expensive and where turf is not available the green may be unplayable for a much longer period since it would have to be replanted. Even where the disease is not serious enough to kill the grass on the greens, it may take a long time for the grass to recover. Weeds are apt to develop in the weakened patches because of the absence of competition from the grass. Greens have been observed where large areas of the grass have been replaced by clover because the weakened condition of the grass, due to snow-mold, allowed the clover to crowd in. This increases the already expensive problem of weed control.

The disease is noticeable as soon as the snow melts. When the snow melts, dead areas are found in the turf. These dead areas are

irregularly circular and from a few inches to a foot or more in diameter. In severe cases the patches may run together to cover large areas. The patches are usually a whitish gray in color, the leaves having a bleached appearance and when wet the leaves feel slimy. These patches develop under the snow as the snow is melting. At that stage they are covered with an aerial mycelium. When the conditions remain favorable for its development, during a long period, the aerial mycelium may be very abundant so that the leaves are matted together forming a thick layer over the patch. Under this layer the fungus may continue to develop after the turf has dried, and the grass may be killed outright. When the patches are exposed to the sunlight a pinkish cast becomes apparent on the leaves due to a change in color of the mycelium. Snow-mold patches are readily distinguished from areas of turf killed by other causes which are light brown in color. Patches not having an abundant growth of mycelium are frequently not killed but will recover slowly. The organism usually attacks only the leaves and only when conditions are favorable for a long period does it spread down into the stems and crowns.

On lawns and golf courses the disease occurs on Kentucky blue grass (Poa pratensis), creeping bent (Agrostis pulustris), Annual blue grass (Poa annua), red top (Agrostis alba), velvet bent (Agrostis canina), red fescue (Festuca rubra), and on winter grains, rye (Secalis cereale), wheat (Triticum vulgare) and barley (Hordeum vulgare).

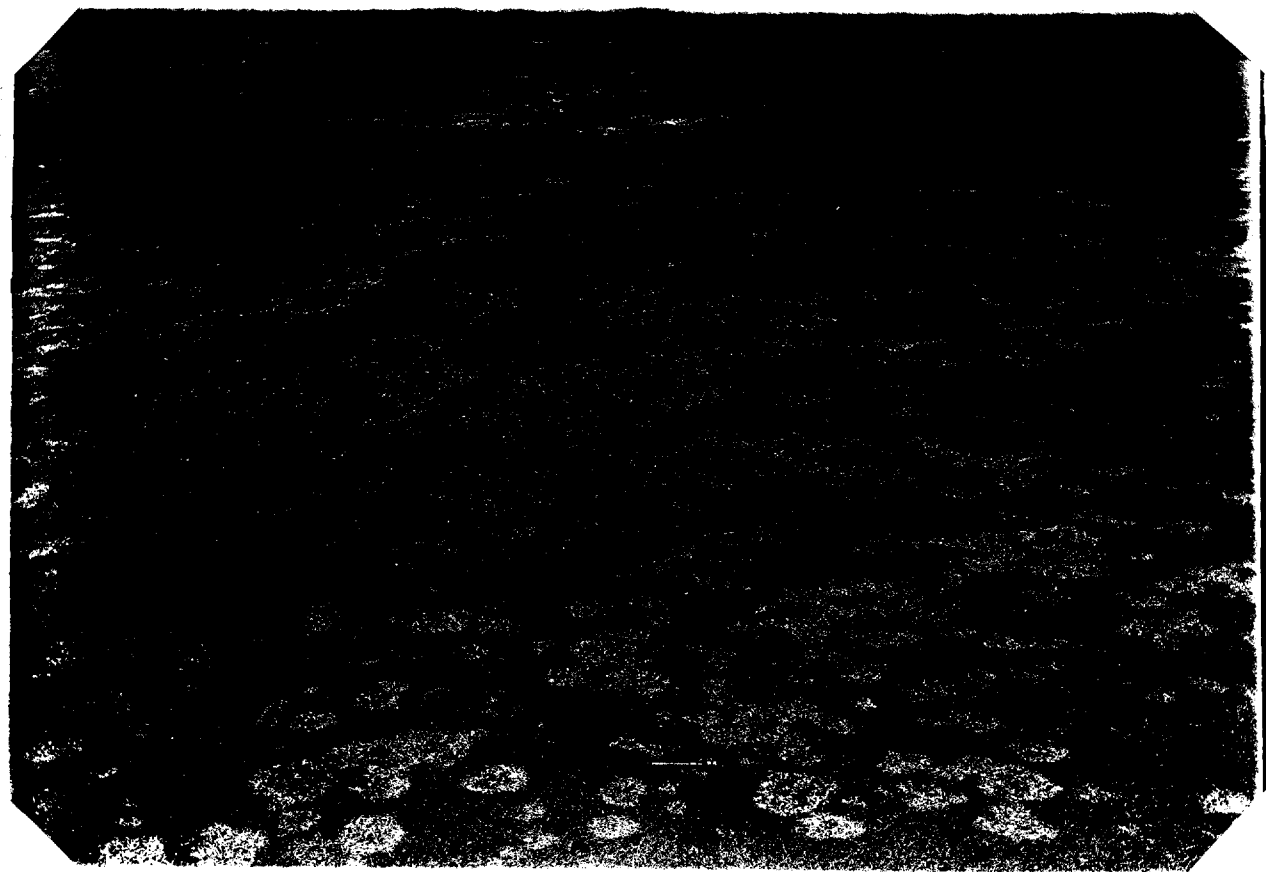


Plate I. Damage to green at Grand Rapids, Michigan caused by Fusarium nivale (Fr.) Ces. The lighter areas are snow-mold patches. The photograph was taken Apr. 3, 1928. The grass on this green did not recover fully until midsummer.

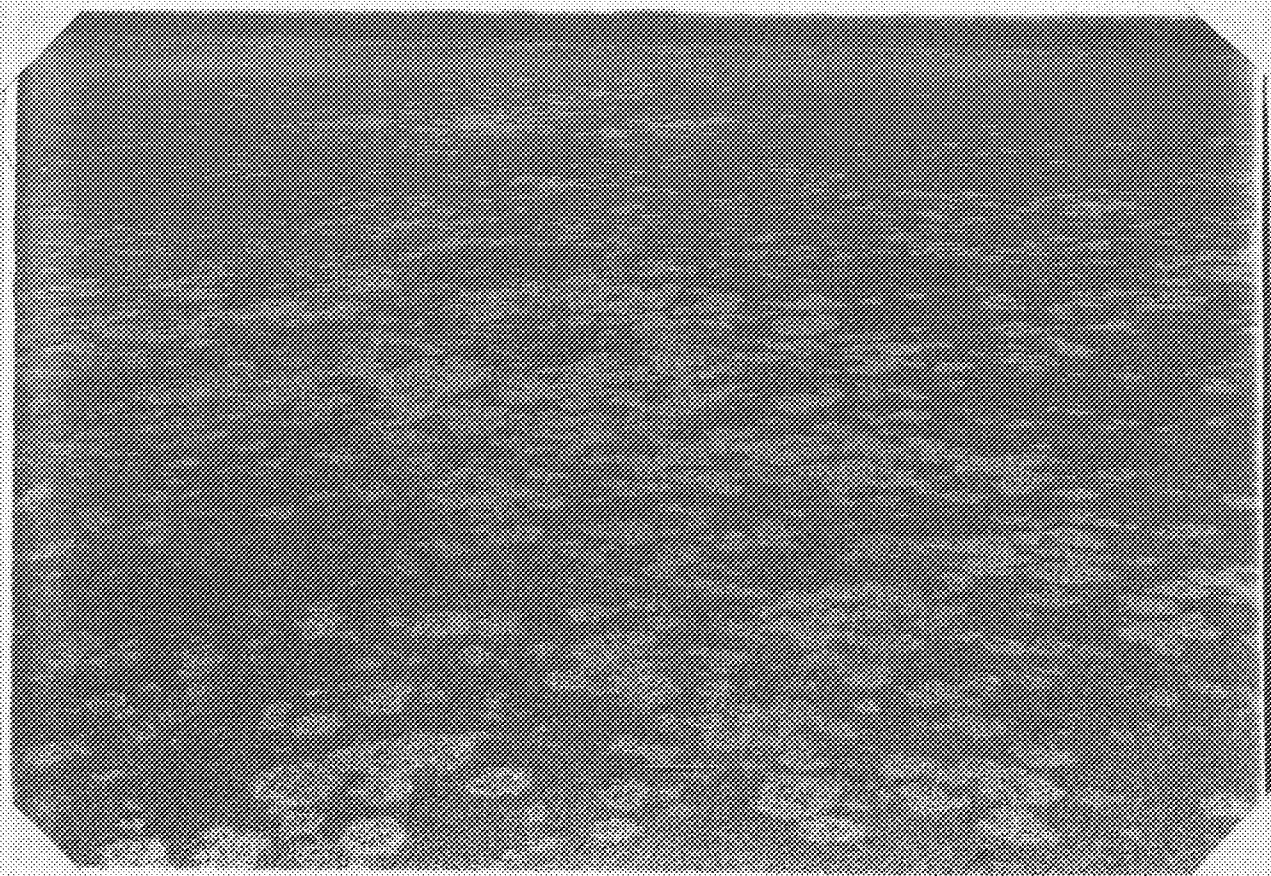


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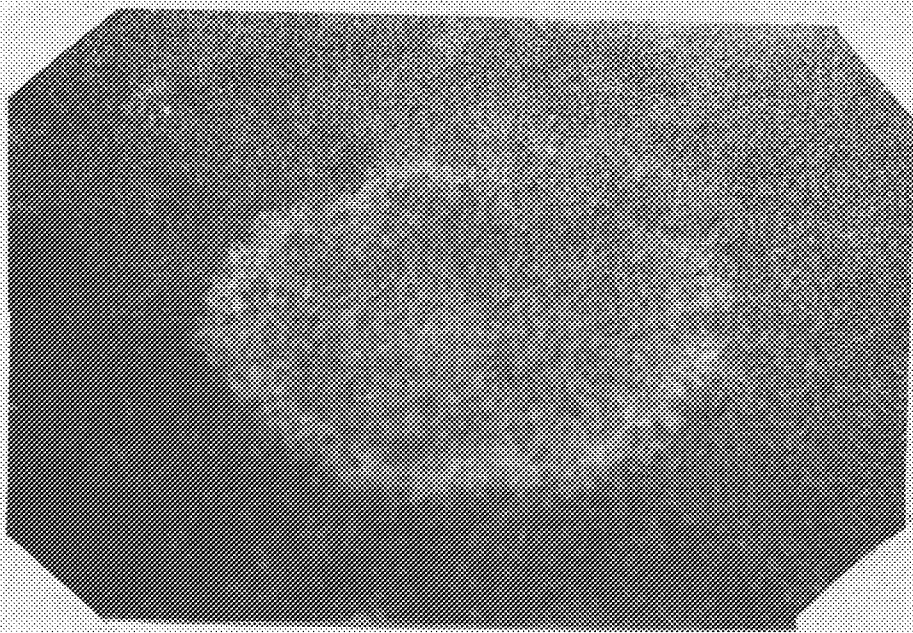


Plate II. Closeup of snow-mold patch. Note ring of white mycelium growing around edge of patch.



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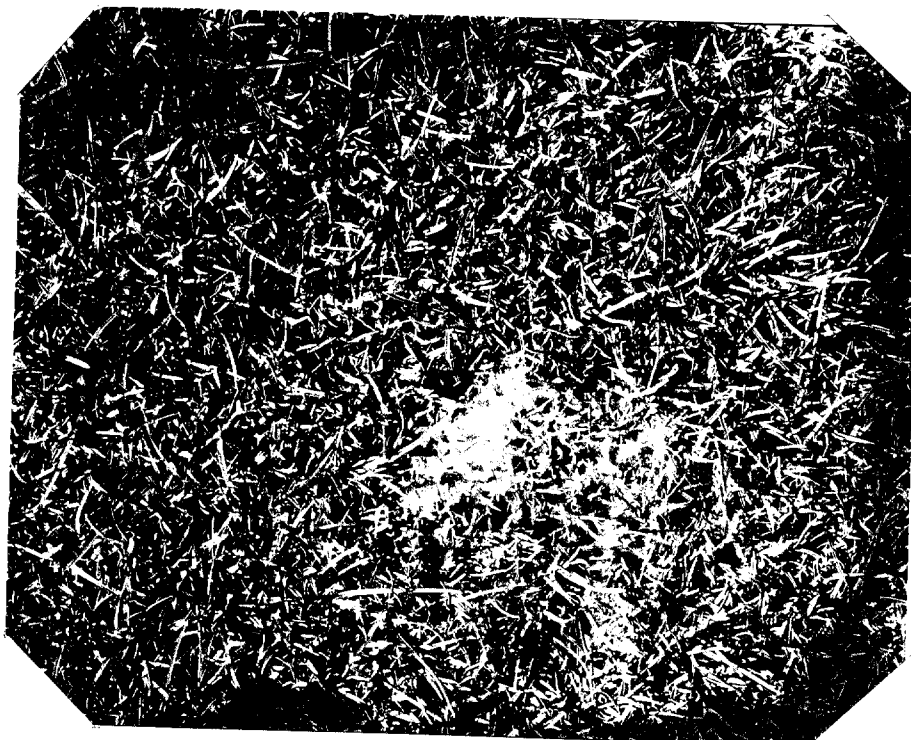


Plate III. Fluffy mycelium of snow-mold organism growing over the leaves in the first stage of a snow-mold patch.

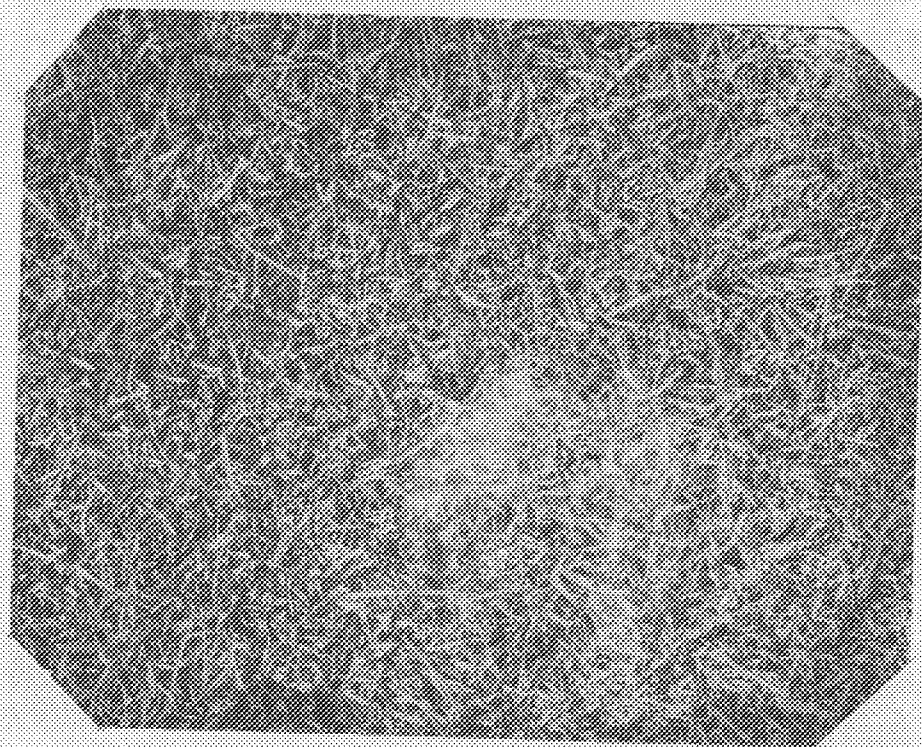


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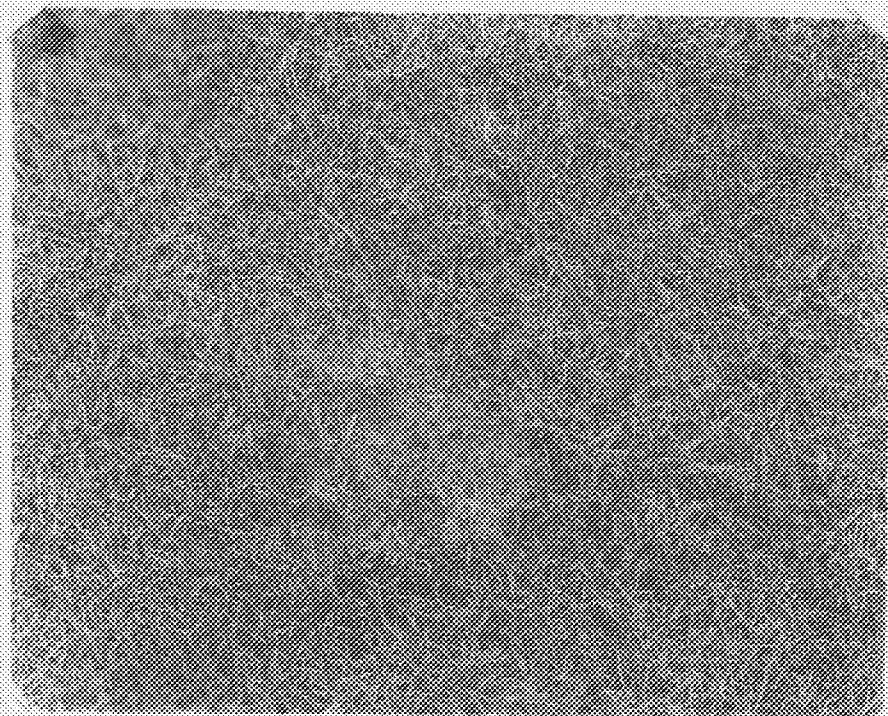


Plate IV. Mycelium of organism matted together with leaves
to form a layer over the turf.

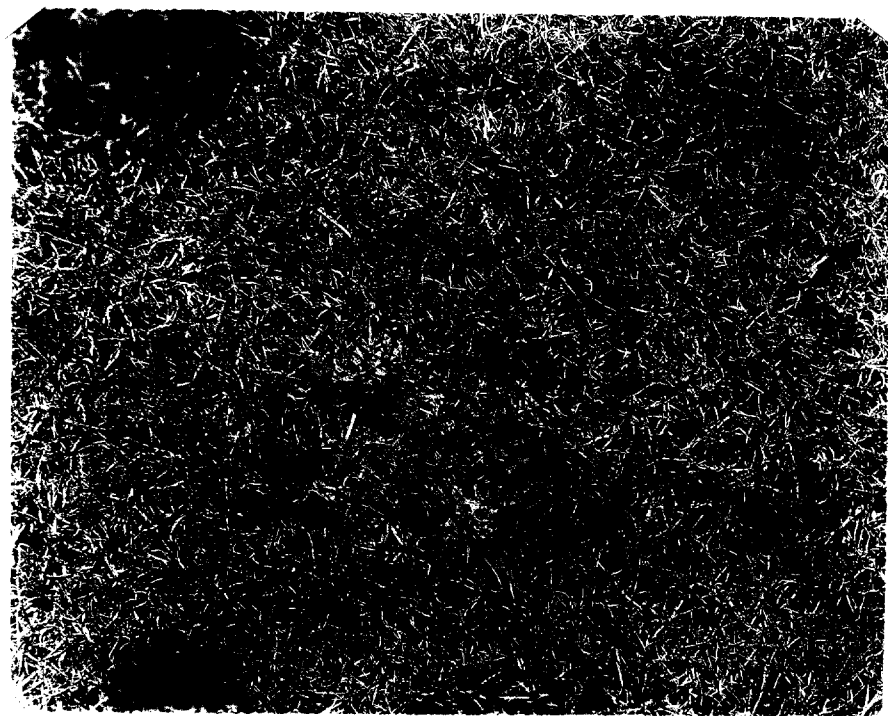


Plate IV. Mycelium of organism matted together with leaves
to form a layer over the turf.

II. REVIEW OF LITERATURE

In Europe snow-mold has been observed for a great many years. The destruction of grain by snow-mold was recorded by Knutberg (8) in 1768 and by Wallerius (24) in 1778. Fries (2) was the first to demonstrate the parasitic nature of the disease. His description was brief and he probably had mixed cultures, but he named the fungus Lanosa nivalis.

Unger (23) gave the first detailed description of snow-mold. He observed it in 1842 on winter grains and on grass lands. He found it in the last days of February and the first days in March, after a wet fall when snow fell on frozen ground. Snow formed a dense cover and the plants, protected from the cold weather of January and February, grew a little under the snow. The plants attacked died in great numbers. Unger thought it strange that snow-mold had not been mentioned more in agriculture literature, but supposed that much of the snow-mold injury had been attributed to winter-killing. It was no rare occurrence for snow-mold to be so destructive that fields had to be plowed in the spring. Unger described the fungus and placed it in Fusisporium or Trichothecium.

Pokorny (14) gave a detailed description of snow-mold on lawns in Vienna. The winter of 1864-65 was unusually severe, with a continuous snow covering. In the spring of 1865 rain commenced in the beginning of March. The weather became very changeable with repeated snows, thaws, rains, and frosts. Snow-mold was first observed on the 12th of March but had appeared some days earlier. The development increased rapidly and the lawns looked as if covered

with cobwebs. At the beginning of April the snow-mold had attained a membranous texture and a grayish color. Pokorny did not find any spores and believed that his organism was different from the one described by Unger. When the lawns became green in the spring, the diseased areas were yellow where the plants had died. The perennial grasses were capable of surviving the disease, while the annual grasses were killed.

Fuckel (3) reported snow-mold on clover fields in 1869. He stated that under the snow the fungus grew on the soil and on the plants. Rostrup (15) stated that snow-mold occurred mostly in sheltered places near hedges, fences, thickets or forests where snow piled up. He was the first to suggest treatment of seed for control.

Sorauer (19, 20, 21) was the first to list snow-mold fungus definitely as a *Fusarium*. He called it *Fusarium nivale*. He was studying frost injury to cereals in the spring of 1900-1901 when he came in contact with snow-mold. He did not believe that seed treatment would be effective, although he found the fungus in the seed, since the fungus was also present in the soil. Where the snow piles up in drifts and melts slowly, cavities are formed between the soil and the snow cover. This produces a calm atmosphere, saturated with moisture and a low temperature which is suitable for the growth of the fungus. The fungus is capable of growing on water but dies when submerged. Sorauer made the first direct inoculation in young plants. He stated that the fungus was a saprophyte in the soil which became parasitic only on plants whose assimilation had been decreased because of certain conditions.

Hiltner (4) stated that snow-mold was most common on rye. He found that fertilizing with stable manure in the fall, favored the development of the disease because of the higher soil temperature that resulted. He found mycelium in the seed usually in the outer layers and in a few cases throughout the endosperm and even in the embryo. But he states that even with infected seed the disease will not occur unless conditions are favorable for the organism and unfavorable for the plants. Hiltner and Ihssen (5) did much work on seed treatments. They tested Bordeaux mixture, formalin, corrosive sublimate, and hot water and found that corrosive sublimate gave them the best results. They thought that the infection through the seed was more important than infection from the soil. They found that Nectria graminicola, later Calonectria graminicola followed the attacks of snow-mold but were unable to produce the perfect form in culture. Snow-mold appeared to be worse on strong vigorous plants probably because strong plants bear up the snow and leave air chambers under the drifts and probably because the stronger plants give more heat due to their greater vitality. Grazing the field reduced the amount of snow-mold. Soils rich in humus had more severe attacks of snow-mold, also manured soils, heavy clays or poorly worked soils. Poor germination, foot rot and head blight were also worse under those conditions.

Mortenson (13) observed that snow-mold was more serious after wet summers. He recommended harrowing the fields in the spring because it helped dry the soil and let air and light into it.

Schaffnit (17) in 1912 published the most important paper on snow-mold. He showed that Fusarium nivale Sor. was a mixed species and redescribed the real Fusarium nivale Cesati. He produced the perfect form of the fungus in pure culture and it proved to be Calonectria graminicola. Fusarium nivale was found to be most common in nature. He made infection experiments showing that Fusarium may cause seedling blight, foot rot and head blight but did not observe these diseases in nature. He stated that the organism was soil borne and the soil was the most important source of infection. He also found snow-mold on grass lawns. He recommended applying Chile saltpeter on the snow to hasten the melting and also rolling and harrowing, and removing small defective grains. He did a great deal of work on the physiology and cultural characteristics of the fungus in the laboratory and also worked with seed treatments. He found corrosive sublimate was very effective but that 1% blue stone and .2% formalin were also effective.

Lindfors (9) recommends seed treatment, removing small grains, not sowing too early or too thickly and fall cutting or grazing because when the plants are too large and strong the heat of their life processes cause an air chamber to form under the snow where the fungus will find conditions favorable to grow. Then in the spring when the snow is gone a dense mat of leaves and mycelium is formed under which the fungus may continue its development and more severely injure the plants. He also recommends loosening the snow ^{mechanically} /or melting it with Chile saltpeter.

Schaffnit (18) in 1920 states that Fusaria occur especially on rye. He distinguishes between primary and secondary infection, the primary infection taking place on the seeds and the secondary infection throughout the rest of the season. Atanasoff (1) disagrees with this and finds that all grains are susceptible to attacks of the fungus. He also states that it is wrong to speak of primary and secondary infection, since it takes place any time of the season when conditions are favorable to the organism and unfavorable to the plant.

Atanasoff (1) speaks of snow-mold as one phase of cereal blights, the other phases being seedling blight, foot rot, and head scab. He states that whenever moisture is high enough, the organism will develop and attack the plants. He discusses the life history in relation to pathogenicity, cultural characteristics of the organisms, climate in relation to disease, varieties in relation to disease, and control measures.

Lindfors (10) in 1924 reported that Fusarium nivale grew best in an acid reaction of pH 5-6, Fusarium culmorum pH 5-6, Fusarium solani pH 6. An abrupt drop was apparent in the growth curve when the acidity of the medium approached neutrality.

III. CAUSAL ORGANISM

A. Description

Snow-mold occurring on winter grains in Europe has been shown to be due mostly to Fusarium (nivale) (Fr) Ces. (Calonectria graminicola (Berk & Brm) Wr) and in part to Fusarium culmorum (W. G. Sm.) Sacc. Schaffnit (17) in examining material from the field found F. minimum (nivale) in 28 out of 29 samples and F. culmorum in the one exception. Lindfors (9) examined at least 200 samples and found F. minimum (nivale) present in all of them. Schaffnit (17) was able to produce snow-mold-like symptoms by inoculating with F. culmorum (W. G. Sm.), F. herbarum (Corda) Fries, F. didymum, F. avenaceum (Fr.) Sacc. and F. lolii as well as F. minimum (nivale) on etiolated or weakened plants. Lindfors (9) believed that F. minimum (nivale) was the most important and that the others may play a minor part in the occurrence of the disease. Atanasoff (1) states, "Whether the presence of this rich fungus growth means or leads to a dying out of the plants or that the plants have been already killed by frost or fungi and that the snow-mold appears merely as a result of the above is something that is not yet fully understood." He further states that he produced the condition, as occurring in the field, in greenhouse experiments by inoculating pots with Gibberella saubinettii (Mont.) Sacc., F. culmorum (W. G. Sm.) Sacc., F. culmorum (W. G. Sm.) Sacc. var. leteius Sherb., F. avenaceum (Fr.) Sacc., Helminthosporium sorokinianum and two other undetermined Helminthosporium spp. However he does not state that his experiments were carried on at a low temperature of near freezing, at which true snow-mold occurs.

The European workers are agreed that F. (nivale) is the most important cause of the disease and in a large majority of the cases is alone associated with it. In numerous inoculations in the greenhouse, in moist chambers kept at from 0° to 5° C. only F. nivale has proven pathogenic. Inoculations have been made with F. (nivale), F. culmorum, F. avenaceum, F. solani and Gibberella saubinettii and numerous other undetermined fungi isolated from diseased grass leaves and only F. (nivale) has proven to be pathogenic. Other soil fungi are often found associated with F. nivale in diseased patches of turf and are at times more conspicuous than the primary organism but in pure culture inoculation these do not produce the disease.

Cultures of F. nivale which were used in inoculation work were isolated from diseased leaves of grass taken from patches showing symptoms of snow-mold. The diseased leaves were placed in petri dishes on water agar and transfers were made from the colonies that developed. The cultures were then grown on potato dextrose agar. Isolations were made with material from Madison, Wis., Grand Rapids, Mich., Chicago, Ill., Minneapolis, Minn., and Duluth, Minn. Single spore cultures were made by the dilution method after the cultures began to sporulate.

The following description of the organism was taken from Atanasoff (1).

Calonectria graminicola (Berk. et Brm.) Wr.

Synonyms

Calonectria graminicola (Berk. et Brm.) Wr.

Wr. 1913, in Phytopath. 3: 34. fig. W.; 3: 231 Tafel 22. Fig. 29-36.

Lanosa nivalis Fries. 1825, in Syst. orb. veget. Part 1.

Nectria graminicola Berk. et Brm., 1859 in Ann. Mag. Nat. Hist. 3 Ser.
3:376.

Fusarium minimum Fuckel 1869 in Symbol. Mycol. S. 370. Pl. I;
Rabenk. Kryptogamenfl. IX Abt. S. 541.

Fusarium nivale autorum pro parte. Schaffnit - Der Schreeschimmel.
Landw. Jahrb. B. 43. 1912.

Fusoma triseptatum Sacc. 1892 in Syll. 10: 566.

Fusoma biseptatum Sacc. 1893 in Grevillea 21: 69, tab. 184, fig. 15;
Syll. 11: 607. 1895.

Fusarium nivale. Sor. pro parte. 1901, in Zeitschr. f. Pflanzenhr.
11: 220.

Fusarium hibernans Lindau, Rabenk. Kryptogamenfl. IX. Abt. S. 542.

Calonectria nivalis Schaffnit, 1913, in Mycol. Centralbl. 2: 257.

Diagnosis: Perithecial stage: Perithecia free or sunken, breaking later on through the substratum, dark brown, round, 160-300 u, usually gregarious. Asci numerous, spindle-shaped, subdorsiventral, straight, 50-60 u long paraphyses present, ascospores septate, 12.5-16 by 2.8-3.5.

Conidial stage: Conidia in mass ochreous to salmon colored, scattered in numerous sporodochia or in pionnotes. Mostly 3 septate, averaging 22.5-25.5 by 3.25-4.1 u; more and up to 6 septate 25-30.5 u by 2.5-4.3 u; 1 and 2 septate common, 14-16 by 3.4-3.8 u. Conidia comma or sickle-shaped, pointed toward apex, basal half slightly thicker, ventral line slightly curved, pedicelation absent or slight.

Typical chlamydospores absent, plectenchymatic stroma thalous or sclerotial, ochreous; aerial mycelium well developed, cottony or thick, in short tufts, originally white, later pink to rose colored.

Habitat. Occurs in United States, Holland, Germany, Denmark, and Sweden and may be elsewhere. It has been reported on wheat, rye, oats, Lolium perenne and Hordeum sat. f. hibernum, on various grasses.

Pathogenicity. One of the important cereal pathogens, causing head blight, seedling blight and foot rot in Europe, seldom in the United States, less seldom in Holland.

B. Studies in Culture

The cultures of the organism studied in this work have been compared by spore measurement and in culture, and were found to agree with the above description. The cultures were grown on cornmeal agar, oatmeal agar, potato dextrose agar, and grass clippings. On cornmeal agar there was very slight aerial mycelial growth which was colorless and very scant. No spores were produced on cornmeal agar. A very abundant mycelial growth developed on oat-meal agar and spores were produced in slimy salmon-colored masses, often covering a large part of the surface of the agar. On potato agar the mycelium was abundant, fluffy and white. Spores were also produced on potato agar as on oat-meal agar. On sterile grass clippings the fungus would cover each leaf with a fluffy white mycelium and in a few cases spores were produced.

When the cultures were kept in darkness from the time they were isolated, there would be no production of spores. But when transferred to diffused light and especially in a moist chamber, sporodochia were formed and great masses of spores would develop. After the spores were once produced in light, the cultures continued to produce spores on subsequent cultures when transfers

of spores were made. Light also changes the color of the mycelium from white to a pinkish color. This change of color due to light was demonstrated on petri dishes, culture tubes and on mycelium on potted grass plants.

Schaffnit (17) found that F. nivale grew between temperatures of 0°-30° C. with an optimum of 22° C. Lindfors (10) and Tu (22) also found that the optimum temperature was 22° C. In the following work three strains of F. nivale isolated from diseased leaves from snow-mold patches were grown in constant temperature chambers at 2, 4, 6, 12, 16, 20, 24, 28, 32, and 36° C. The strains were grown in petri dishes which contained 10 c.c. of potato dextrose agar. This agar was prepared taking the decoction from 200 grams of pared potatoes in a liter of water and adding 17 grams of agar, and 10 grams of dextrose. Transfers of mycelium were made from young petri-dish cultures, and the rate of growth per hour was calculated after 72 hours of growth.

Table (1) gives the rates of growth per hour at the various temperatures and fig. 1. shows the growth curve graphically. The three strains agree generally in their growth curve. The amount of growth at 2° C. indicates that the fungus is adapted to very low temperatures. In general the optimum appears to be about 20° C., all of them growing as well or better at 16° C. as at 24° C. There is a sharp drop in the curve above 24° C. and although there was some growth at 32° C. there was none at 36° C.

C. Infection Experiments

The pathogenicity of the cultures of the organism studied was proven by inoculation of pots of grass plants. All of the

	2	4	8	12	16	20	24	28	32	36
A	.7	.8	1.1	1.8	2.3	2.9	1.9	1.0	.6	0
B	.6	.8	1.1	2.2	2.6	3.5	2.8	1.5	.5	0
C	.9	1.1	1.6	2.1	3.5	3.7	3.2	1.9	.5	0

Table I. Rates of growth per hour of three strains of Fusarium nivale (Fr.) Ces. on potato dextrose agar. The figures represent millimeters of radial growth.

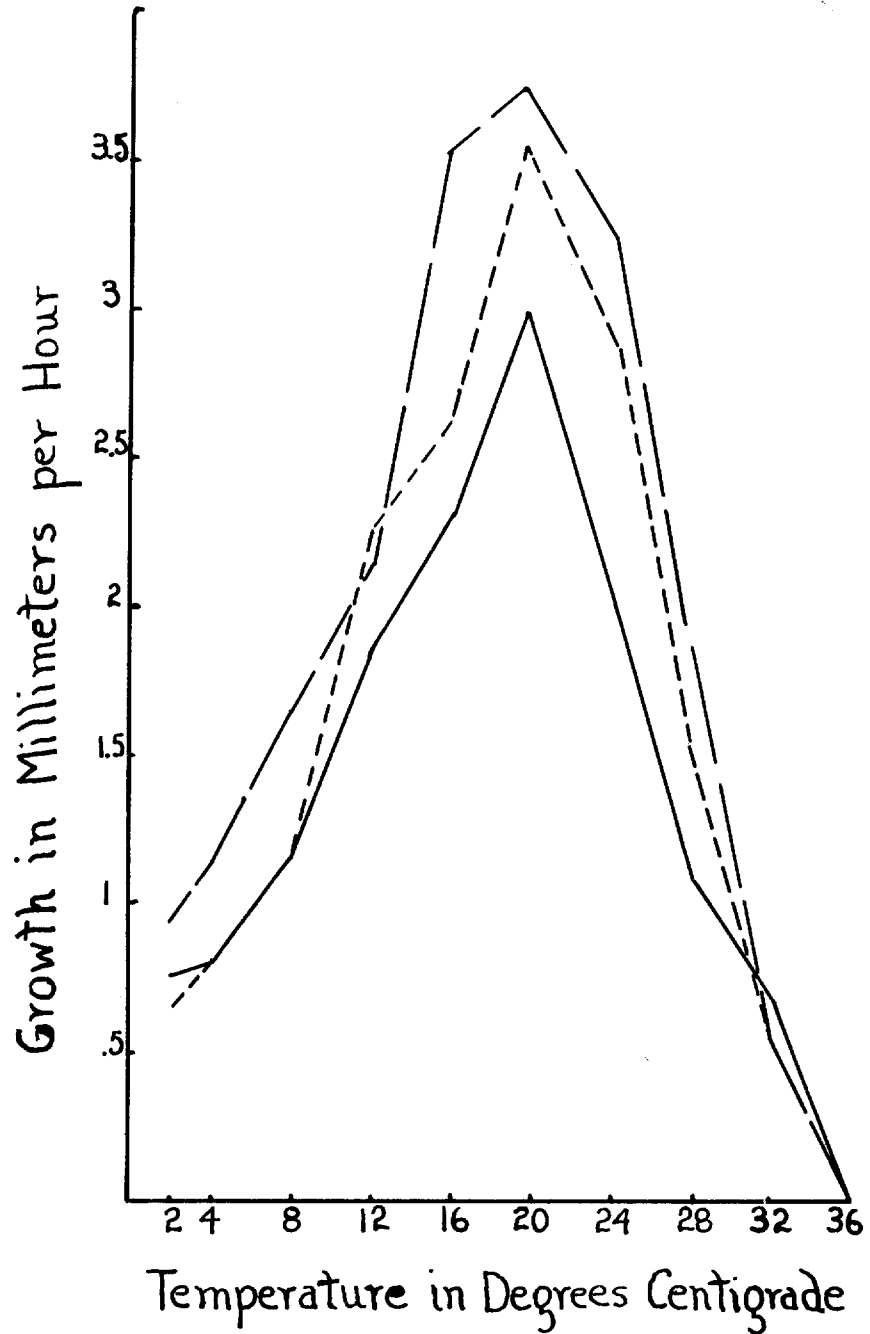


Fig. 1. Effect of temperature on the rate of growth of three strains of *Fusarium nivale* (Fr.) Ces. on potato dextrose agar. Note their essential likeness with a rather slow rise up to 10° then more rapid up to the optimum of about 20° with a rapid fall above 24°. This is in contrast with most cultural parasitic fungi which show an optimum at about 24-30° C.

grasses were grown in autoclaved pots and soil. The seed was treated with 1-320 formalin for 15 minutes. The grasses were grown in the greenhouse and clipped from time to time, so that the growth was never over 2 inches high.

The strains of the fungus to be inoculated were grown on sterilized grass clippings in culture tubes, until the mycelium had grown throughout the clippings in the tube. A portion of the clippings was then transferred to the center of a pot of grass. The inoculum was held up about $1\frac{1}{2}$ inches above the surface of the soil by the leaves. The pots were then placed in moist chambers. The moist chambers were kept in a lean-to located outside of the greenhouse, where the winter temperature kept below freezing most of the time. Then 250 watt heating lamps were wrapped in cotton and placed in a pan of water in the bottom of the chamber. These lamps were connected with a relay which had a thermostat connection, so that the temperature could be kept constant. Whenever the temperature in the chamber fell below the desired temperature the heating element would be lighted and a fog of moisture would rise from the pan of water. This gave an abundant supply of moisture in the chamber.

Most of the inoculations were made in a chamber kept at from 0° to 5° C. since best results were obtained at that temperature. Successful inoculations were made on creeping bent (Agrostis pulustris), fescue (Festuca rubra) Kentucky blue grass (Poa pratensis), red top (Agrostis alba), barley (Hordeum vulgare), oats (Avena sativa), wheat (Triticum vulgare), and rye (Secalis cereale). All of the inoculations were made on seedlings, except creeping bent, where old sod was brought into the greenhouse and potted.

In some cases infection of the leaves had taken place within 2 days after inoculation. In other cases a longer time was necessary. When the amount of moisture was cut down the infection was very slight, and the spread of the organism from leaf to leaf was very slow. The mycelium of the organism spread very quickly when the moisture was above the saturation point, until the whole pot would be covered with mycelium as in plate V.

Inoculations were made in chambers kept at temperatures of 0°-5° C., 5°-10°, 10°-15° and 15°-20° C. The best results were obtained in the 0°-5° C. chamber. The mycelium spread more quickly and was more abundant and fluffier. In the 5°-10° chamber there was also a good growth of mycelium and a rapid spread of the fungus over the leaves. At 10°-15° the development was much slower and the mycelium was not so abundant. At 15°-20° there was a very small amount of infection near the inoculum. There was no aerial mycelium and after three weeks very slight spread of organism.

Inoculations were also made on pots which had treatments of corrosive sublimate at the same rate as turf is treated in field experiments. These inoculations were made a week after the pots had been treated and were made in the same way as the above inoculation; that is by placing the inoculum up in the leaves of the plants. These inoculations were successful and the grass was killed by the organism. In other pots inoculations were made and then the corrosive sublimate was sprayed on the leaves, after the organism had spread over numerous leaves. The treatment killed the organism, and there was no further spread of the disease over a period of several weeks. These experiments indicate that the fungicide treatments used to combat snow-mold, act as a partial

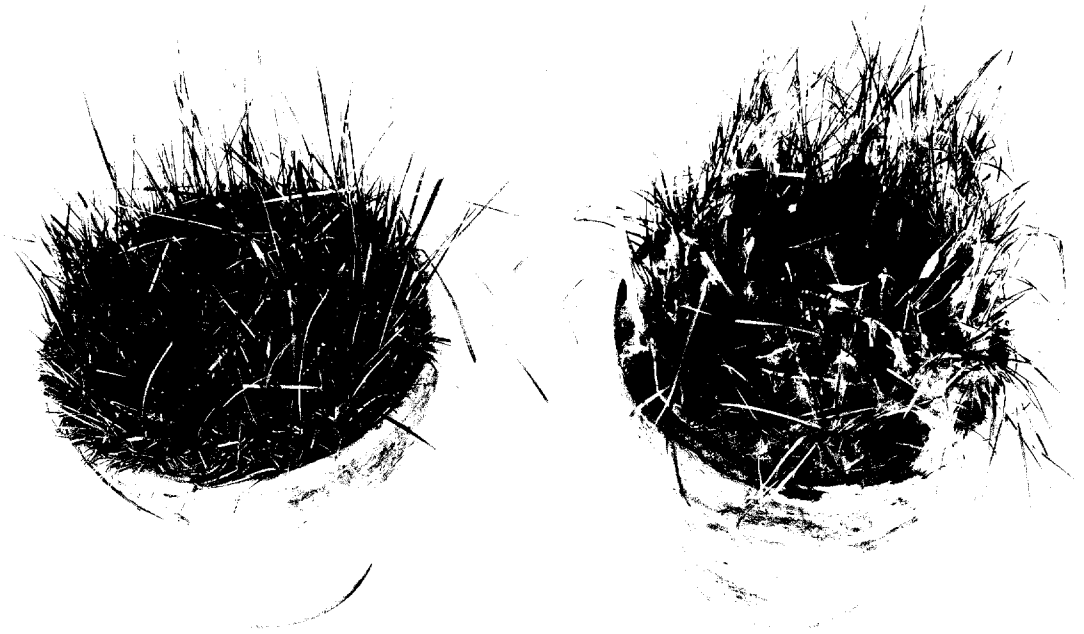


Plate V. Pot of Kentucky blue grass inoculated with Fusarium nivale on right. Control on left. Note abundance of aerial mycelium on diseased pot.



Plate V. Pot of Kentucky blue grass inoculated with Fusarium nivale on right. Control on left. Note abundance of arial mycelium on diseased pot.

disinfectant of the soil rather than rendering the host plants immune from infection.

D. Histological Studies

An effort has been made to work out the method of penetration of the organism and the relation of the fungus and host tissue. Material was obtained from plants inoculated with pure cultures in the greenhouse. Kentucky blue grass, red top and creeping bent were used. The material was fixed in formalin acetic alcohol, Carnoy's fixative, medium chrom acetic, and Juel's fixative. These were prepared as follows: formalin acetic alcohol - formalin 25 cc., glacial acetic acid 10 cc., 50% alcohol 400 cc.; Carnoy's - chloroform 180 cc., glacial acetic acid 60 cc., absolute alcohol 120 cc.; medium chrom acetic, 1% chromic acid 30 cc., acetic acid .7 cc., distilled water 99 cc.; Juel's - zinc chloride 2 gm., glacial acetic acid 2 cc., 50% alcohol 100 cc. Juel's fixative gave the best results although some good preparations were also made with formalin acetic alcohol and Carnoy's fixative. Chrom acetic fixative plasmolyzed the tissues quite severely. After fixing, the material was imbedded and longitudinal sections were cut.

The preparations were stained at first with safranin and fast green which gave some differentiation between host and parasite. Later the material was stained with Delafield's haematoxylin which gave the best results of any of the stains for the purpose of the work.

Upon examination of the prepared slides, it was found that the mycelium developed along the outside of the leaf. When a hypha reached a stoma it enlarged at the terminal end and one or more

infecting hypha would develop down through the stomatal opening into the intercellular spaces. No direct penetration through the epidermal cells was observed, until after the cells within the leaf had collapsed and there was an abundant development of mycelium. The mycelium develops faster along the surface of the leaf than it does within the leaf tissue, so that new infections through stomata would take place along the whole length of the leaf until it became wholly infected. Where temperature and moisture conditions are not favorable for abundant aerial mycelium the infection of the leaf would be slower because of less mycelium growing along the surface.

Ihssen (7) found that the hyphae traveled through the intercellular spaces close to the vessels and this was observed to be the case. The growth of the organism in the tissue was intercellular with much branching until numerous hyphae extended in all directions. Later the cells collapse and the fungus almost fills the space occupied by the collapsed cells. The fungus may then penetrate into the vessels.

Ihssen (7) also observed that sporodochia developed through the stomata in rows. These were found when the leaf was badly diseased. An abundant growth of mycelium at first occurred through the stomata. This mycelium developed into sporodochia which bore great masses of spores on club shaped sporophores. In prepared slides most of the spores had become detached during their preparation. In some cases the sporodochia became so large that they covered considerable surface of the leaf, so that two or three stomata would be involved. After the leaf was badly diseased, penetration through the epidermis took place in great abundance. When a leaf is badly diseased nearly all of the parenchyma cells collapse and the vessels only are left intact.

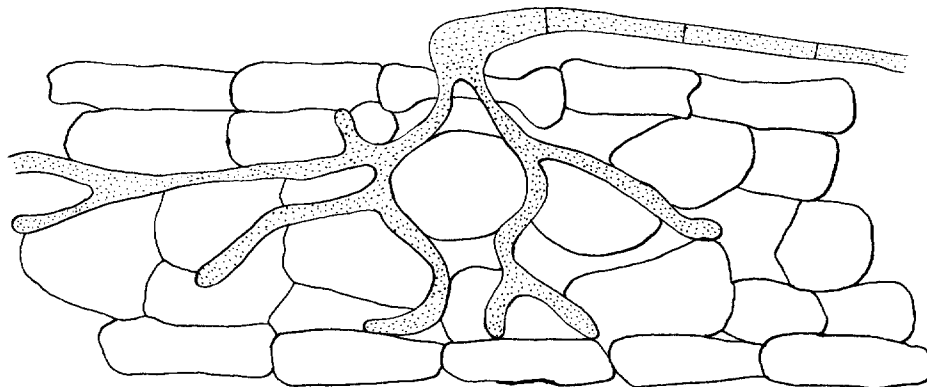


Fig. 2. Somewhat diagrammatic sketch of the penetration of F. nivale (Fr.) Ces. through a stoma on a leaf of red top. From a longitudinal section. Note the intercellular progress of the fungus through the tissue.



Plate VI. Infection of a leaf through a stoma. Note the enlargement of the end of the infecting hypha and the intercellular course of the invading hyphae.

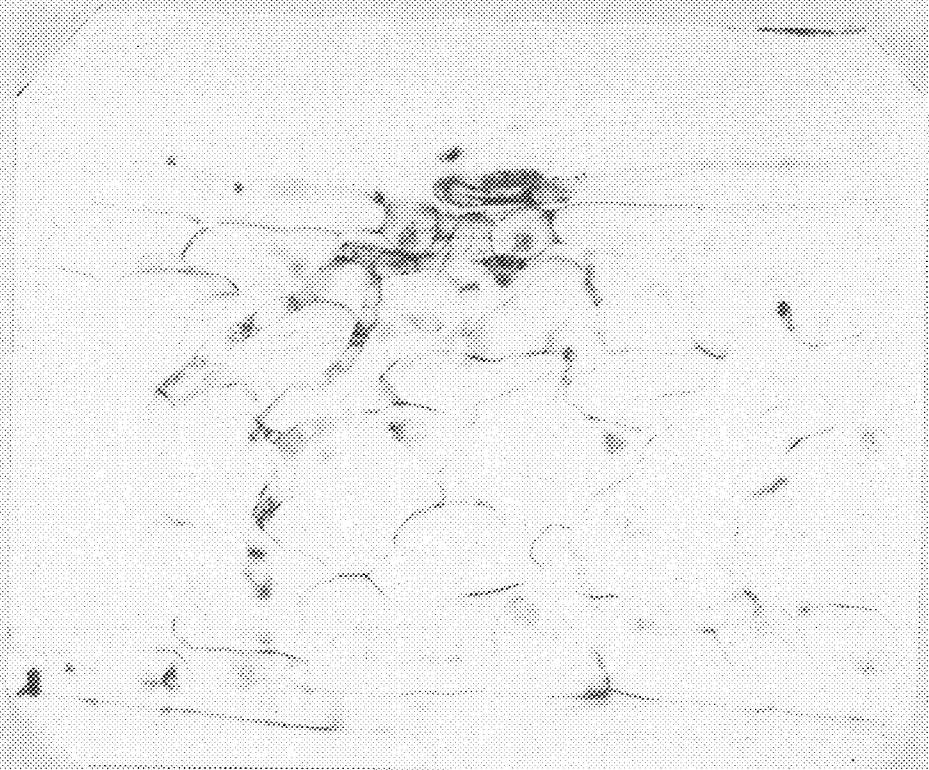


Plate VI. Infection of a leaf through a stoma. Note the enlargement of the end of the infecting hypha and the intercellular course of the invading hyphae.

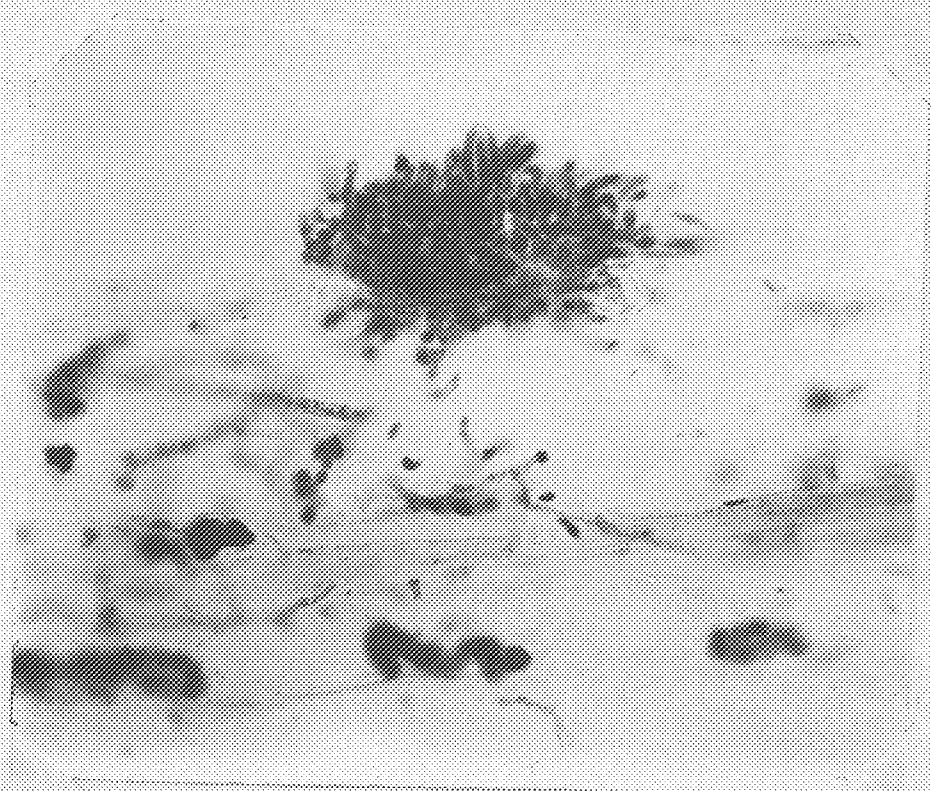


Plate VII. A sporeochium as it occurs on a stoma. The guard cell of the stoma is located just below the sporeochium.



Plate VII. A sporodochium as it occurs on a stoma. The guard cell of the stoma is located just below the sporodochium.



Plate VIII. A young sporodochium situated on a stoma. Note aerial mycelium of organism extending out over surface of leaf. The mycelium is still mostly intercellular in the host tissue.

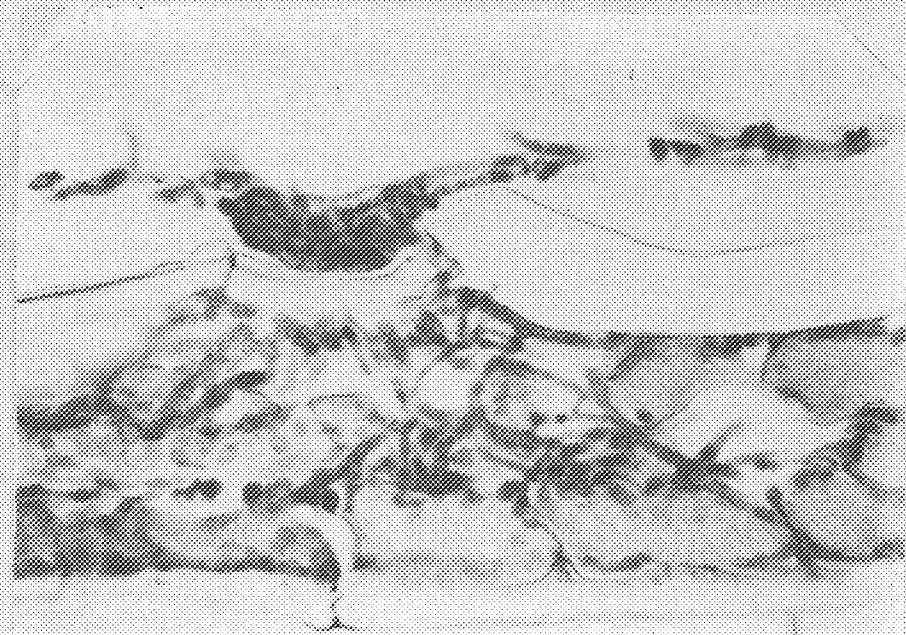


Plate VIII. A young sporodochium situated on a stoma. Note serial mycelium of organism extending out over surface of leaf. The mycelium is still mostly intercellular in the host tissue.

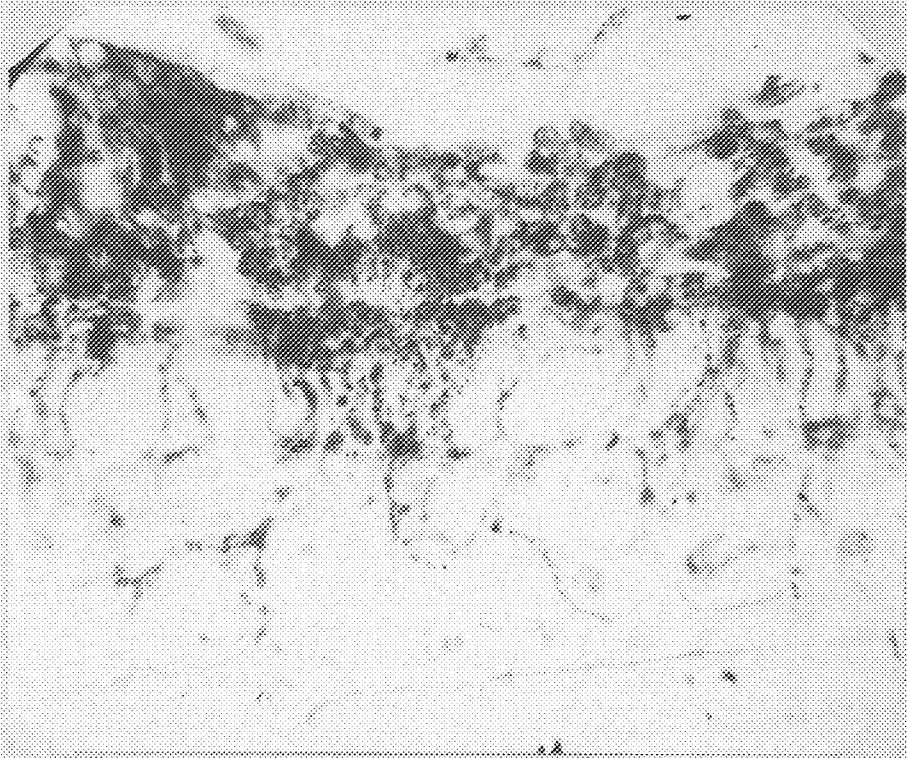


Table IX. Sporodochial mass covering surface of leaf. The host tissue has mostly collapsed and the sporodochia from several stomata have united.

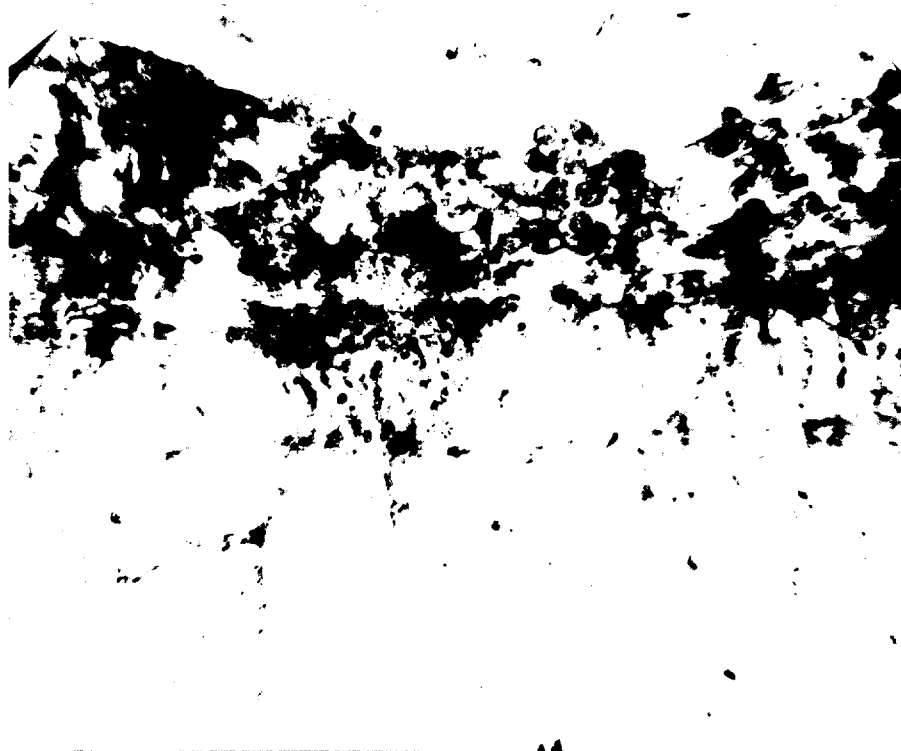


Table IX. Sporochial mass covering surface of leaf.
The host tissue has mostly collapsed and
the sporochia from several stomata have
united.

IV. INFLUENCE OF WEATHER ON OCCURRENCE OF DISEASE

Weather conditions play a very important part in the development of the disease. Continuous snow-cover throughout the winter, and a long cold spring seem to encourage severe attacks. This is especially true where snow falls early in the fall before the ground is frozen. Unger (23) reported snow-mold in 1842 after a wet fall, when snow fell on unfrozen ground. Large amounts of snow fell and formed a thick cover over the ground. Pokorney (14) also found snow-mold to be very severe on lawns during the spring of 1865 after a winter of continuous snow covering and a slow thaw in the spring. The spring was long and with repeated snowfalls, slow thaws, and cold rains.

Sorauer (19-20) states that the organism grows continually during mild winters and stops only when it freezes. He explains that cavities are formed between the snow cover and the ground and in these cavities there is a saturated atmosphere and low temperature, which are suitable for the development of the fungus.

Hiltner and Ihssen (5) found snow-mold worse on slopes facing north where the snow melted more slowly in the spring. Mortenson (13) observed that the disease was worse after wet summers, when the moisture in the ground was abundant as the snow fell. Atanasoff (1) appears to believe that abundant moisture is the most important factor in the development of the disease, and that the temperature is not important. However from inoculation experiments it has been shown that the lower temperature of from 0° - 5° C. gave the most severe attacks.

It has been observed in this country that the disease on golf

courses and fairways is more serious after winters of continuous snow, and that the snow falling on unfrozen ground encourages its development. In Minneapolis, Minn., in the fall of 1927 when the snow fell before the ground was frozen, very severe attacks of snow-mold were found on some of the putting greens. The same was found true in Grand Rapids, Mich. the same year. In the latter case the snow melted before the end of the year and the disease was apparent in the latter part of December.

However, deep snow is not always necessary for the development of the disease. During the winter of 1927-28 at Madison, Wis. many greens on some of the courses were bare much of the time. Snow-mold developed and was active on these greens. The weather was cold and cloudy much of the time and apparently there was enough moisture in the ground and in the air for the organism to grow.

Sunlight and dry winds soon stop the development of the organism after the snow has disappeared. Where there has been an abundant growth of mycelium and the leaves are matted together, air and sunlight are kept out. This holds the moisture in the turf and the organism continues to grow and injures the turf severely. Hiltner and Ihssen (5) Atanasoff (1) and Schaffnit (17) record that the mycelium disappears as soon as the sunlight or air currents come in contact with it and the plants then begin to recover. In turf, where the plants are closely knit together, sunlight does not penetrate and the fungus may continue to live. Whenever a cloudy day occurs, the fungus can again become active and spread. Greenkeepers have made a practice of brushing these patches to break the mat of leaves and mycelium. This dries the patch and lets the sunlight in, so that the

development of the organism is stopped.

Temperature records have been taken under the snow for two winters. These show that while the snow is on the ground the temperature is almost constantly at the freezing point. As soon as the snow melts and the ground is bare, the temperature of the soil varies more with the air temperature. During the winter of 1928-29 temperatures were recorded under the snow at Wayzata, Minn. The thermograph bulb was placed under a covering of straw and during the winter was buried under a thick layer of snow. The temperature remained almost constant at 0° C., although the air temperature was as low as -20° F. In the winter of 1930-31 soil temperatures have been recorded at Madison, Wis. and in this case the thermograph bulb was placed just under the surface of the turf. When snow was present the temperature remained nearly constant at 0° C. no matter what the air temperature was. When the snow melts, the soil temperature begins to vary with the air temperature. These temperature records indicate that the development of the organism takes place at 0° C. This has been borne out by inoculation in the greenhouse where best results were obtained from 0° to 5° C.

V. INFLUENCE OF SOIL AND CONDITION OF GRASS ON OCCURRENCE OF DISEASE

The condition of soil may affect the occurrence of the disease in two ways, first, by its influence on the growth of the plants, and second, by its influence on the development of the organism. Hiltner (4) found the disease worse on heavy clay soil, poorly worked, poorly drained, and on soil rich in humus. Hiltner (6) also found that manuring and covering with straw encouraged the development of the organism, because of the higher soil temperatures that resulted.

In rich soils there is a very luxuriant growth of the plants late in the fall just before the snow falls. When the grass is fertilized late, there is a marked growth of grass. Plots were fertilized with ammonium sulphate on November 6, 1930 in Chicago, Ill. on putting green grass and when observed on December 6, it had a very dark green appearance in contrast to the checks which had not been fertilized and were very decidedly brownish in color. Even though the temperature is very low, the grass will grow when stimulated by fertilizer.

This condition encourages the development of snow-mold. Sorauer (19-20) mentions that the fungus attacks the leaves mainly because of their thinner epidermis and rich plasma. Hiltner (6) and Ihssen (5) found that snow-mold was worse on fields where the plants were larger and held the snow up from the ground, so that cavities were formed where the fungus could develop. They also state that the stronger plants give off more heat due to their greater vitality. They also found that grazing in the fall reduced the amount of snow-mold because of the smaller amount of leaf surface

which remained when the snow fell. Lindfors (9) recommended late seeding, low rates of seeding, and cutting or grazing in the fall, so that the leaf area would not be too great. He too explains it on the basis of higher temperature under the snow and formation of air chambers in which the organism can develop. He also states that when leaves and mycelium are formed under which the fungus may continue its development and more severely injure the plants.

It has been the practice of some greenkeepers especially in the vicinity of Minneapolis, Minn. to cover their greens with straw during the winter. In many cases this practice has led to very serious damage from snow-mold. Other greenkeepers who fertilize in the fall or have a great deal of organic matter in their top dressing, have trouble with attacks of the disease.

In order to determine what effect fall fertilization or straw covering would have on the occurrence of disease, experiments were made on turf or putting greens during the winters of 1928-29 and 1929-30.

In the fall of 1928 plots were laid out on green No. 14 at Woodhill Country Club, Wayzata, Minn. 25 miles out of Minneapolis, Minn. These plots were 8' by 20' having an area of 80 sq. ft. All combinations of corrosive sublimate, fertilizer and straw were applied so that the experiment included plots treated with corrosive sublimate; corrosive sublimate and straw; corrosive sublimate and fertilizer; corrosive sublimate, fertilizer and straw; straw and check plots. The use of corrosive sublimate and calomel for control measures will be taken up later in this paper.

The corrosive sublimate was applied at the rate of 3 oz. per 1000 sq. ft. It was diluted with a quart of sand and broadcast over the area of the plot. The fertilizer used was activated sludge, manufactured by the Milwaukee Sewage Disposal Commission, and ammonium sulphate. This was applied at the rate of 38 lbs. of sludge and $6\frac{1}{2}$ lbs. of ammonium sulphate per 1000 sq. ft. This was also broadcast on the plots. The straw was applied December 1 in a layer about two inches thick.

Table 2 gives the results of this experiment. The figures represent the percentage of the area which was killed by the disease. These percentages were determined in the spring after the straw had been removed April 3, 1929. From the table it will be noted that where no straw had been applied there was no disease. Where straw was applied alone, there was a complete kill of the grass due to snow-mold. Where the straw and the fertilizer had both been applied there was also 100% kill. Only where corrosive sublimate had been applied under the straw was there any healthy turf. On these plots there was 5% of the area of the turf injured by disease. In the plots where corrosive sublimate and fertilizer had been applied before covered with straw, 50% of the turf had been killed.

This experiment was repeated in the winter of 1929-30 at the Masonic Country Club of Michigan at Comstock, Mich. In this case plots were laid out which were 4' by 8' or 32 sq. ft. All combinations of corrosive sublimate, fertilizer and straw were also applied to these plots and one series was made where calomel was substituted for corrosive sublimate. The corrosive sublimate and calomel were applied at the rate of 3 oz. per 1000 sq. ft. and broadcast on with sand.

	Covered with straw	Not covered
Check	100	0
Corrosive sublimate	5	0
Corrosive sublimate and fertilizer	50	0
Fertilizer	100	0
Check	100	0

Table II. Results of field experiments at Wayzata, Minnesota.
The figures represent percent of turf covered by
diseased areas.

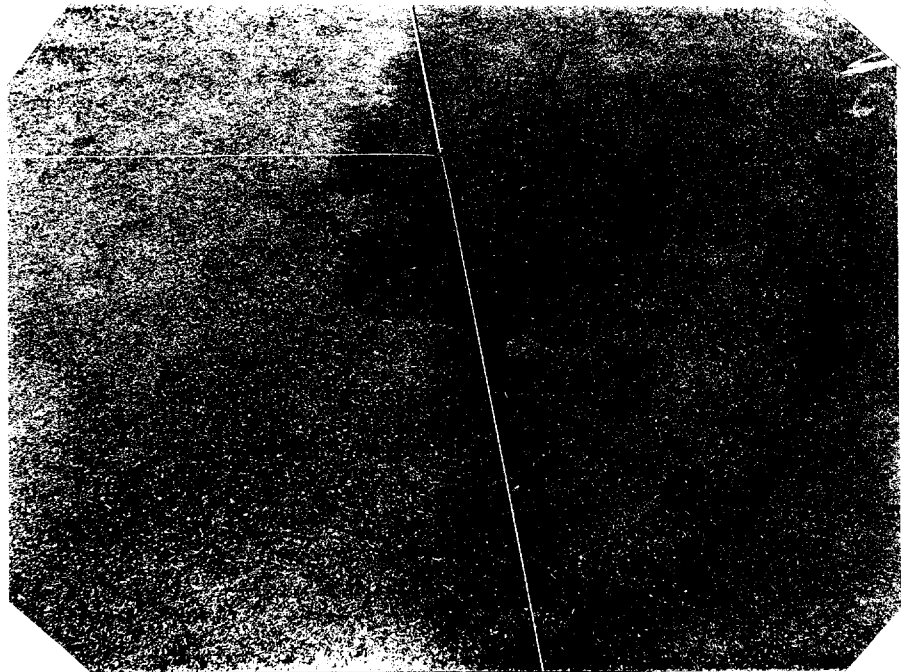


Plate X. Plots on left of line were covered with straw during winter. The lighter area is the dead grass killed by snow-mold. The darker area on the left is healthy green grass.

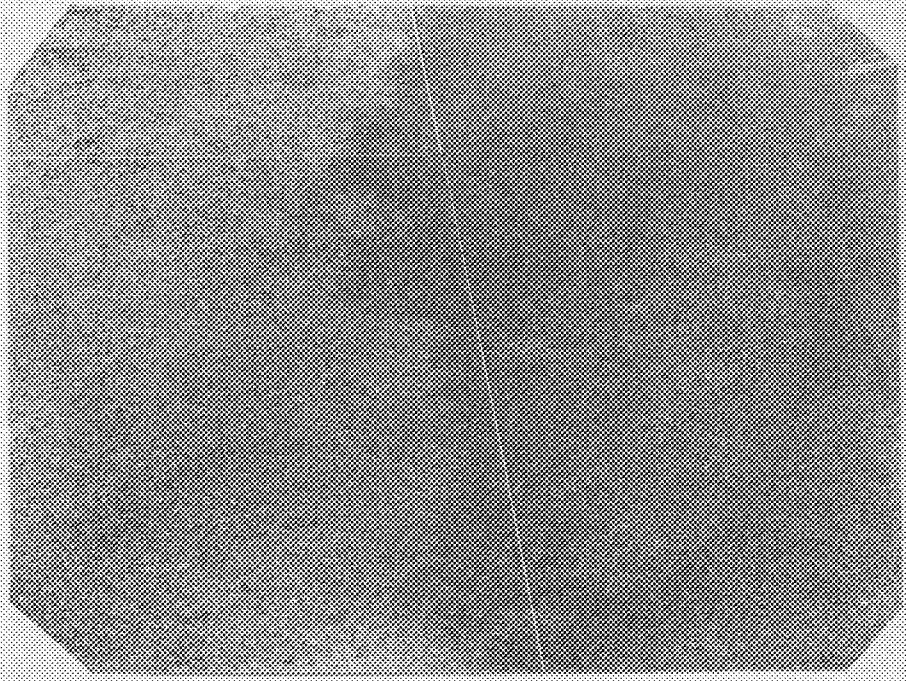


Plate X. Plots on left of line were covered with straw during winter. The lighter area is the dead grass killed by snow-mold. The darker area on the left is healthy green grass.

The fertilizer was activated sludge and ammonium sulphate at the rates of 25 lb. of sludge and 5 lbs. ammonium sulphate per 1000 sq. ft.

The results of this experiment are given in table 3, and show that fertilizing increased the amount of disease about 100% over the unfertilized areas. Straw also increased the amount of snow-mold to a great extent. The experiment shows that the efficiency of control by chemicals is greatly reduced by fertilizers and straw covering.

It is apparent that a strong growth of grass in the fall tends to encourage serious attacks of the disease. But it is doubtful whether this is due to the increase in temperature under the snow. Temperature records show that the temperature under the snow is very constant and does not vary during the time snow is present. The temperature under a covering of straw was the same as the uncovered plots when snow was present, so that the covering of straw evidently did not raise the temperature. It is more probable that the soft succulent growth of growing grass is more favorable for infection by the organism than is the harder drier tissue of plants that are not growing. Sorauer (20) said that the leaves were infected most because of the rich plasma and that is probably the case. The absence of snow-mold on grains in this country has been thought to be due to the winter freezes before the snow fell. These freezes stop growth and the tissues harden. In Europe snow often falls before frosts have stopped the growth of plants. On putting greens the grass is stimulated by fertilizer far into the fall, and the growth is still succulent when snow falls.

The large amount of organic matter in putting green turf also encourages the disease. Where straw is applied and kept wet by the

snow cover, there is an abundance of material on which the fungus can develop saprophytically. From this substratum the mycelium of the organism can spread out to the leaves of the grass plants.

	Fertilized	Not Fertilized
Check	40	20
Calomel	20	5
Calomel and straw	70	30
Straw	90	50
Corrosive sublimate and straw	30	20
Corrosive sublimate	10	2
Check	40	20

Table III. Results of field experiments at Comstock, Michigan.
The figures represent percentage of turf covered
by diseased areas.



Plate XI. The two plots in the background received fertilizer in the fall. The two on the left of the line received corrosive sublimate. Note amount of disease on the fertilized plots.



Plate XI. The two plots in the background received fertilizer in the fall. The two on the left of the line received corrosive sublimate. Note amount of disease on the fertilized plots.

VI. FIELD EXPERIMENTS ON CONTROL MEASURES

Control measures for snow-mold as it occurs on winter grains have been developed in Europe. Rostrup (16) first suggested the possibility of seed treatment in 1893, but it was not until 1907 that Hiltner and Ihssen (5) were successful in developing an effective seed treatment. They found that corrosive sublimate gave them the best results. Since that time much work has been done on seed treatments.

However since grass turfs are maintained year after year and new seed is not introduced into the turf, seed treatment would not be effective. The question of whether the organism remains viable in the soil, has been much disputed in Europe. Sorauer (21) and Schaffnit (17) believed that the organism could live in the soil. Hiltner and Ihssen (5) and Lindfors (9) did not believe so. But it is probable that in turf, conditions are more favorable for the fungus to live and certainly it must live in the soil and even increase from year to year. This is indicated by the fact that new turfs are not affected as much as older turf and that the disease usually occurs on the same location with increasing severity year after year.

Diseases of grasses in turf have been controlled for the last few years, by broadcasting or spraying fungicides on the turf. Monteith (12) has been able to control effectively large brown patch, caused by Rhizoctonia solani Kühn, and small brown patch caused by Sclerotium spp. by treating the turf with mercury compounds. The most practical of these, have been corrosive sublimate, calomel, and chlorophenol mercury. For this reason when a control for snow-

mold was sought, attention was turned to these chemicals.

Monteith (11) made the first preliminary tests during the winter of 1926-27. In the fall of 1926, he treated plots of turf on greens on a golf course at Madison, Wis. He applied rates of 1 and 2 oz. per 1000 sq. ft. These treatments were effective in preventing snow-mold in the spring of 1927.

Since then, experiments have been conducted to determine the rate of fungicide that would be adequate and effective to control the disease. In these experiments plots were laid out on greens of golf courses at Grand Rapids, Mich. and in Minneapolis, Minn. district. These plots were applied at the rates of 1, 2 and 3 oz. per 1000 sq. ft. The plots were separated by two-foot strips of untreated turf to serve as checks. The chemicals were applied by carefully mixing with one-half bucket of sand or fine compost for each plot. This mixture was broadcast over the plot. The checks were treated with the same rate of sand or compost without the fungicide.

Table 4 shows the results of four of the experimental plots. The figures represent percentages of area of the turf covered by patches of disease. The largest rate was not entirely effective in most cases. However, where the disease did occur on these plots and where it occurs on greens treated with a 3 oz. per 1000 sq. ft. rate, it is rarely severe and the turf soon recovers. The 2 oz. rate decreased the amount of the disease considerably, and here too the severity of the injury was not as great. The 1 oz. rate was not very effective, although it did lessen the severity of the disease to some extent. In the checks the amount of disease was not only greater, but the injury to the turf was more severe and the turf took longer to recover from attacks of the disease.

Golf courses which had been troubled with snow-mold for several years, have for the last two years been making a practice of treating all of their greens with either calomel or corrosive sublimate and have been successful in preventing serious attacks. Calomel and corrosive sublimate are almost equally as effective and are both used to a wide extent by greenkeepers. Some greenkeepers treat only those greens which are likely to be attacked and thus are saved the expense of treating all of their greens.

	Grand Rapids		Woodhill Interlachen	
	No. 13	No. 1	No. 10	No. 14
3 oz. Corrosive sublimate	5	5	0	5
3 oz. Calomel	5	20	0	5
2 oz. Corrosive sublimate	40	40	0	20
2 oz. Calomel	20	40	0	20
1 oz. Corrosive sublimate	80	60	20	40
1 oz. Calomel	40	20	40	20
Checks	90	90	80	60

Table IV. Results of field experiments on control on the greens at the golf courses mentioned above. The figures represent percent of diseased turf.



Plate XII. Plots showing control of the disease with calomel. The plot on the left was treated in the fall. On the right is the check plot which had no treatment.

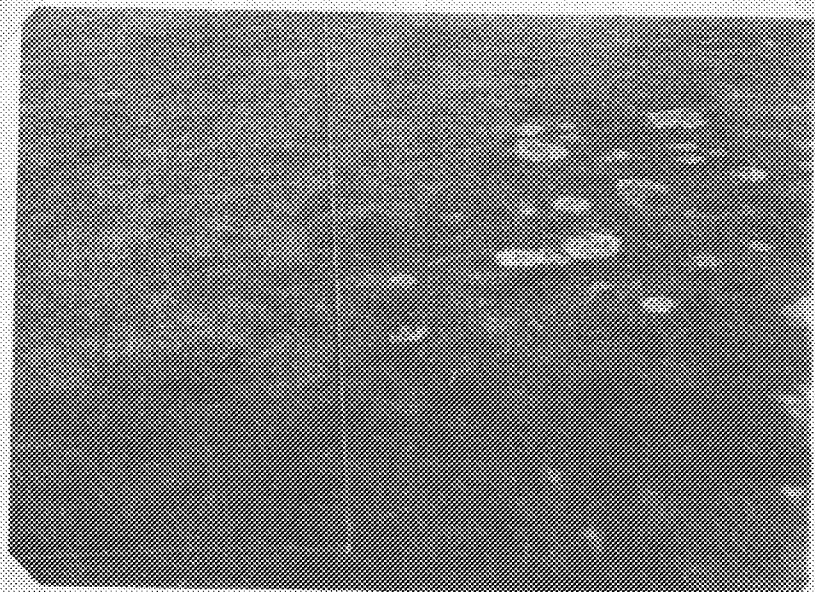


Plate XII. Plots showing control of the disease with calomel. The plot on the left was treated in the fall. On the right is the check plot which had no treatment.

VII. VARIATION OF RESISTANCE TO DISEASE IN STRAINS OF GRASS

It has been observed that there is a difference in the susceptibility of varieties of winter grains, to attacks of Fusarium blight. Hiltner and Ihssen (5), Lindfors (9), and Atanasoff (1) mention this difference in resistance. The same has been observed to be true with different grasses used on golf courses.

The amount of snow-mold that may occur on a golf course may be due to several factors. It may be due to the location of the greens, that is whether or not they are sheltered from sun and wind and are covered with deep drifts for long periods in the winter. On such greens the snow melts slowly in the spring. Poor drainage may make attacks of the disease more severe. The methods of culture used by the greenkeeper is another factor. If he fertilizes heavily late in the fall or supplies an abundance of organic matter, it is probable that he will be troubled with attacks of snow-mold.

The resistance of the grass will also be a factor in the occurrence of disease on any particular golf course. It has been observed that some strains of creeping bent are very susceptible while others are very resistant. The Columbia type strains are very susceptible (Plate XIII). This type makes a very thin turf which is entirely killed by numerous patches of snow-mold. The turf does not recover in these patches, but must fill in from the edges of the patch when growing weather comes. This type of grass is in use on several golf courses in Grand Rapids and Minneapolis, and is one of the reasons why those particular courses are troubled with snow-mold. The Washington strain of creeping bent is often attacked by snow-mold, but is rarely serious enough to warrant resodding. Usually the



Plate XIII. Plots showing variation in resistance to disease. Note amount of disease on plot of Columbia creeping bent on right. The plot on the left is the more resistant Virginia creeping bent.



Plate XIII. Plots showing variation in resistance to disease. Note amount of disease on plot of Columbia creeping bent on right. The plot on the left is the more resistant Virginia creeping bent.

injury disappears in the spring. Washington bent makes a very thick mat of turf with short internodes in the stems and many nodes. Creeping bent roots at each node so that if any of the nodes survive the attack of snow-mold organism, they send out roots and shoots, and the grass recovers. Columbia type strains have longer internodes, fewer stolons and fewer nodes. There will be less chance that this grass would recover from the disease. That is not the whole story, however, because the Columbia regularly has a much greater percentage of area covered by disease than the Washington strain.

Seaside creeping bent is one which is propagated by seed while the others are propagated by stolons. This is also a susceptible strain. This grass has been observed on golf courses, and is usually severely attacked by disease. On demonstration plots in Detroit and Grand Rapids where several grasses are grown in turf in 10' by 10' plots side by side, the seaside bent has been observed to be severely attacked while Colonial bent beside it, did not have a spot of disease. Plate XIV shows the difference in resistance of Colonial and seaside bent.

Metropolitan bent is quite resistant to attacks of disease. On the demonstration plots, where snow-mold has appeared on other grasses, there has been none apparent on this strain. At Wayzata in 1929, Metropolitan and a wild strain found on the golf course there, were growing side by side. The wild strain had four or five times as much disease as the Metropolitan strain.

Fescue is also susceptible. On golf courses where fescue greens were planted, the fescue has been eliminated by snow-mold. This is one of the limiting factors in the growing of fescue greens in this country.



Plate XIV. Plots showing variation in resistance.
On right is the susceptible Seaside
creeping bent and on the left is the
resistant colonial bent.



Plate XIV. Plots showing variation in resistance.
On right is the susceptible Seaside
creeping bent and on the left is the
resistant colonial bent.

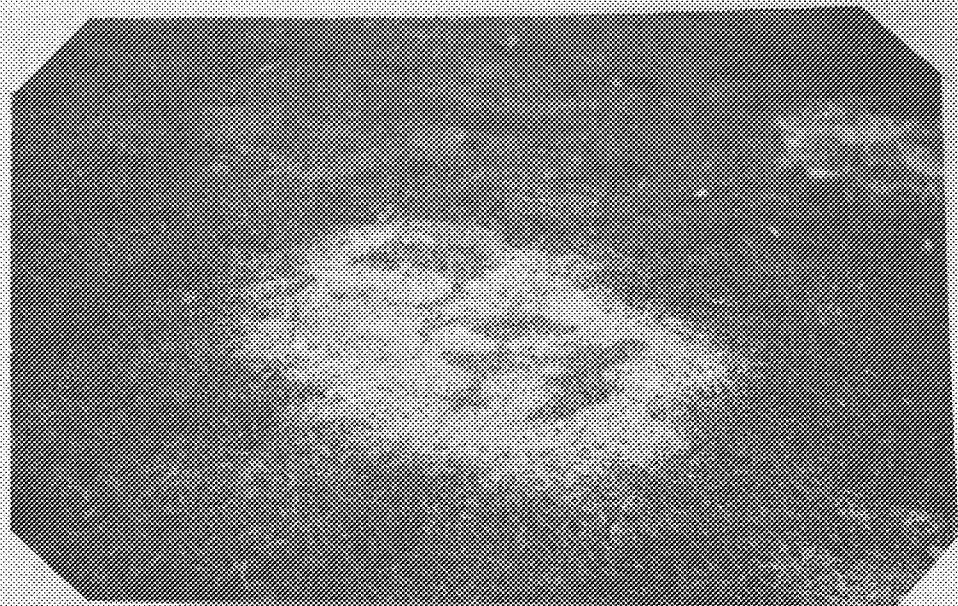


Plate XV. Patch of wild creeping bent with two strains mixed together, one susceptible and the other resistant. The lighter area in the patch is the susceptible strain diseased with snow-mold and the darker area is the resistant strain which has no disease.



Plate XV. Patch of wild creeping bent with two strains mixed together, one susceptible and the other resistant. The lighter area in the patch is the susceptible strain diseased with snow-mold and the darker area is the resistant strain which has no disease.

VIII. DISCUSSION AND CONCLUSIONS

The organism causing snow-mold has been discussed in Europe for many years. Schaffnit (17) and Lindfors (9) are agreed that F. nivale is the most important cause of the disease in nature. This was shown by the work of both investigators in which the great majority of their isolations showed the presence of F. nivale alone, Schaffnit was able to infect plants and produce snow-mold-like symptoms with F. culmorum, F. herbarum, F. didymum, F. avenaceum and F. lolii. These inoculations were successful only when he allowed the plants to become etiolated by growing them in blue light. In ordinary day light and in red or yellow light the inoculations were unsuccessful except with F. nivale. In the work reported in a previous chapter, inoculations at temperatures of 0° to 5° C. on healthy grass grown from seed in the greenhouse were successful only with F. nivale. Numerous other inoculations were unsuccessful. Apparently F. nivale has the ability to grow at a lower temperature and is a stronger parasite at that low temperature.

Atanasoff (1) also reported inoculations on plants with other organisms to produce snow-mold-like symptoms. He used Gibberella saubinettii, F. culmorum, F. culmorum var letius, F. avenaceum, Helminthosporium sorokinianum and two other Helminthosporium spp. However he does not state that his inoculations were made at a low temperature. F. nivale has proven parasitic at a temperature of near freezing but it has not been proven that any other organism would be parasitic under the same conditions. The records of temperatures under the snow indicate that F. nivale is parasitic at temperatures near the freezing point. After the snow disappears in

the spring and the temperature rises the disease does not develop further.

Snow-mold on greens usually occurs in isolated patches. Each patch develops from a center where the organism must have been present in the turf. The number of such points of foci seem to be limited on a green. This indicates that the organism does not persist in any great abundance in the turf, but that there are only a few points from which the fungus can develop. Although during the snow-mold season much of the area of the turf is covered by disease, the following spring the organism is again present in only a few isolated points. Evidently most of the organism succumbs during the warmer periods of the year.

F. nivale as other cereal blight organisms, is mainly a saprophyte. In turf when conditions become favorable for its growth, it becomes active and lives on dead organic matter which is very abundant. An aerial mycelium develops which covers the leaves and the hyphae penetrate through the stomata. The organism would be classed as weakly parasitic. Sorauer (21) stated that the organism attacked the leaves mainly, seeming to prefer those organs with a thin epidermis and a rich plasma. It has been observed that the organism infects only the leaves both in the field and in greenhouse inoculations. It is probable that it can more easily gain entrance in the leaves because of the presence of stomata and for that reason cannot penetrate the stem.

The progress of the organism through the tissues of the leaf is intercellular until the cells begin to collapse and then it becomes intracellular. The organism grows faster on the outside of the leaf than it does within the leaf so that new infections take place over

the whole surface of the leaf. After the mycelium is well developed within the leaf, sporodochia are formed on the stomata. On the sporodochia, spores are produced in great numbers. When moist the spore masses have a slimy salmon-colored appearance. When they are dried, they have a reddish color. In potted plant experiments, the spread of the organism was by means of aerial mycelium which grows from leaf to leaf. Patches in the field have been observed where the mycelium spreads outward around the edge of the patch, growing on living and dead leaves.

Hiltner and Ihssen (5) found snow-mold worse on strong vigorous plants and on manured soils or where straw had been applied. They recommended grazing the fields in the fall because it reduced the amount of leaf area. Lindfors (9) also recommended reducing the amount of leaf area by later seeding, fall grazing or cutting. Both investigators explain it on the basis that larger plants give off more heat due to the greater amount of respiration. However the temperature under the snow does not vary from the freezing point and is not higher where there is greater leaf area or where straw has been applied. The greater amount of snow-mold under those conditions may be in part due to the ease with which the organism can spread from leaf to leaf. Where the leaves are abundant and large the mycelium overgrows the leaves and they become matted together to form a layer over the plants. Under this layer the organism can develop as long as temperature remains low, even after the snow has disappeared.

The absence of serious attacks of snow-mold on winter grains in this country is probably due to the winter freezes that occur before snow falls. In Europe, snow falls before many frosts have and the

growth of the plants has not been stopped. In this country these freezes stop the growth of the plants and the tissue of the leaves becomes mature. When the plants are actively growing and have a soft succulent growth, there is rapid assimilation and respiration. These processes are balanced and as the tissues mature they are slowed and there is a storage of carbohydrates and a loss of water from the cells. Such mature tissue is apparently not susceptible to attacks of the disease. But when the plants are still in an active vegetative state and snow occurs, light is cut off, stopping assimilation, and respiration continues so that the carbohydrate reserves are reduced and the tissues are a better medium for the growth of the fungus. Under these conditions the plants are more susceptible to attacks of the disease. On putting greens it has been apparent that strong growth of grass in the fall encourages attacks of snow-mold. This is not due to increased temperature and cannot be explained in all cases by increase in leaf tissue because grass is clipped very short on greens in the fall. Plots treated with fertilizer were cut the same height as the untreated plots so that the amount of leaf area was almost the same. It is probable that the greater amount of disease was due to the immaturity of the tissue of the leaves which made it more favorable for the development of the fungus than the more mature tissue of plants that are not growing. On putting greens grass is stimulated by fertilizers late in the fall and is not allowed to mature before snow-fall thus making it susceptible to attacks of snow-mold.

Field experiments on control have shown that corrosive sublimate and calomel are effective in preventing attacks of the disease. In-

oculation experiments in the greenhouse have indicated that the action of the mercury compounds is a partial disinfection of the soil rather than rendering the plants immune from the disease. The organism is able to infect leaves grown in soil which had been treated with corrosive sublimate. Where the fungus is not wholly exterminated by the fungicide, it is able to grow on the leaves on the surface of the turf. It is able then to spread from leaf to leaf, but is not able to penetrate deeply into the turf because of the presence of chemical. For this reason when treated areas are diseased they are not seriously injured. The fungus does not grow deeply in the turf and the grass soon recovers when growing weather begins.

IX. SUMMARY

1. Snow-mold is a disease occurring on winter grains in northern Europe and on turf grasses in the United States and Canada. It is particularly important on golf courses in the United States and Canada. The disease occurs on turf as irregularly circular patches of dead grass. These appear as the snow is melting. They are usually from a few inches to a foot or more in diameter and may run together to cover large areas. The patches are a whitish gray color or may have a pinkish tinge. Individual plants have a bleached appearance and feel slimy when wet. On golf courses the disease occurs on Kentucky blue grass, annual blue grass, red top, red fescue, creeping bent and velvet bent.

2. A review of the development of our knowledge of the disease is given without attempting to record all the work that has been published on snow-mold.

3. Snow-mold on golf courses in this country was found to be caused by Fusarium nivale (Fr.) Ces. (Fusarium minimum Fuckel) (Calonectria graminicola (Berk and Brn) Wr.). The organism grows well on oatmeal and potato agar and on sterile grass clippings. Spores are formed on sporodochia when the culture is exposed to diffused light which also changes the color of the mycelium from white to pink. Temperature studies showed that the organism grew at temperatures from 2° to 32° C. with an optimum of about 20° C.

4. Creeping bent, Kentucky blue grass, red top, red fescue, barley, rye, wheat and oats were artificially inoculated in the low temperature moist chambers. The most rapid and injurious infections took place in chambers kept at 0-5° C. At 15-20° C. infections were slight and very slow. Inoculations were also successful on pots of

grass grown in soil that had been treated with corrosive sublimate at the same rate as field experiments which gave control. Pots were artificially infected with the disease and then sprayed with corrosive sublimate which checked further progress of the organism.

5. Diseased leaves were fixed and inbedded, and slides were prepared. The organism was found to enter the leaves through the stomata. Its progress through the tissue was intercellular until the cells began to collapse and then it became intracellular. After the mycelium became abundant in the tissue, sporodochia were formed on the leaf over the stomatal openings so that they occurred in rows on the leaf.

6. Temperature records under the snow showed that the organism grew at about the freezing point. Observations indicated that climatic conditions greatly influenced the amount of snow-mold. These conditions that favored attacks of the disease were: abundant moisture in the fall, snow falling on unfrozen ground, deep snow and a cold, wet, long spring.

7. Applying fertilizer late in the fall was found to make attacks of snow-mold more serious. Where the soil had abundant organic matter or where the greens were covered with straw there was also an increase of the disease.

8. Field experiments showed that the disease could be controlled by treating the turf with corrosive sublimate and calomel at the rate of 3 Oz. per 1000 sq. ft. in the fall of the year. Applications of fungicide at rates of 1 and 23 per 1000 sq. ft. were only partially effective.

9. It was found that there was a difference in the susceptibility to the disease in the grasses used on golf courses. Strains of grass

growing side by side would have very different amounts of disease.

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SNOWMOLD OF TURF GRASSES AS CAUSED BY
FUSARIUM NIVALE

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SNOWMOLD OF TURF GRASSES AS CAUSED BY FUSARIUM NIVALE¹

ARNOLD S. DAHL²

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INTRODUCTION

Winterkilling of turf grasses presents an important problem in the maintenance of fine turf, particularly in the northern States. Winterkilling is a general term that has been used in referring to injuries to turf caused by poor drainage, to drying of grass due to cold dry winds, late freezes after the grass has begun to grow in the spring, and to fungous disease. The disease, of parasitic origin, occurs during the winter and early spring and is called snowmold because of its association with snow. The purpose of this study was to determine the cause of this disease and investigate the relation between the host and the parasite. It was also desired to determine the climatic and soil conditions that favored its development, influences of cultural practices, and to work out some means of control.

GEOGRAPHIC DISTRIBUTION AND HOST RANGE

Snowmold is prevalent in Europe, where it occurs on winter grains and lawns in Germany, Denmark, Norway, Sweden, and Russia. The destruction of grain was recorded by Knutberg (7) in 1768. Some of the early studies of the disease and its causal organism were made by Fries (2), Unger (19), Pokorny (13), Fuckel (3), and Sorauer (15, 16, 17).

In North America it is prevalent on golf courses and lawns in the northern tier of States and in Canada. It is most important in Wisconsin, Minnesota, Michigan, and Canada, but also occurs with severity in other States in the same latitude. In the States south of the northern tier it is frequently found in a few places but causes less damage. It has been reported as far south as Virginia.

DESCRIPTION OF THE DISEASE

Most of the damage to turf in this country occurs on putting greens of golf courses, but it also occurs on fairways and lawns. When it occurs on

¹ This work was done in the Department of Plant Pathology, University of Wisconsin, with the support of the United States Golf Association Green Section.

² The writer wishes to acknowledge his indebtedness to Dr. John Monteith, Jr., of the United States Golf Association Green Section, for his suggestions and aid during the progress of this investigation and to Prof. L. R. Jones and other members of the faculty of the department of Plant Pathology, University of Wisconsin, and to the faculty members of the Department of Plant Pathology, University of Minnesota, for cooperation and assistance.

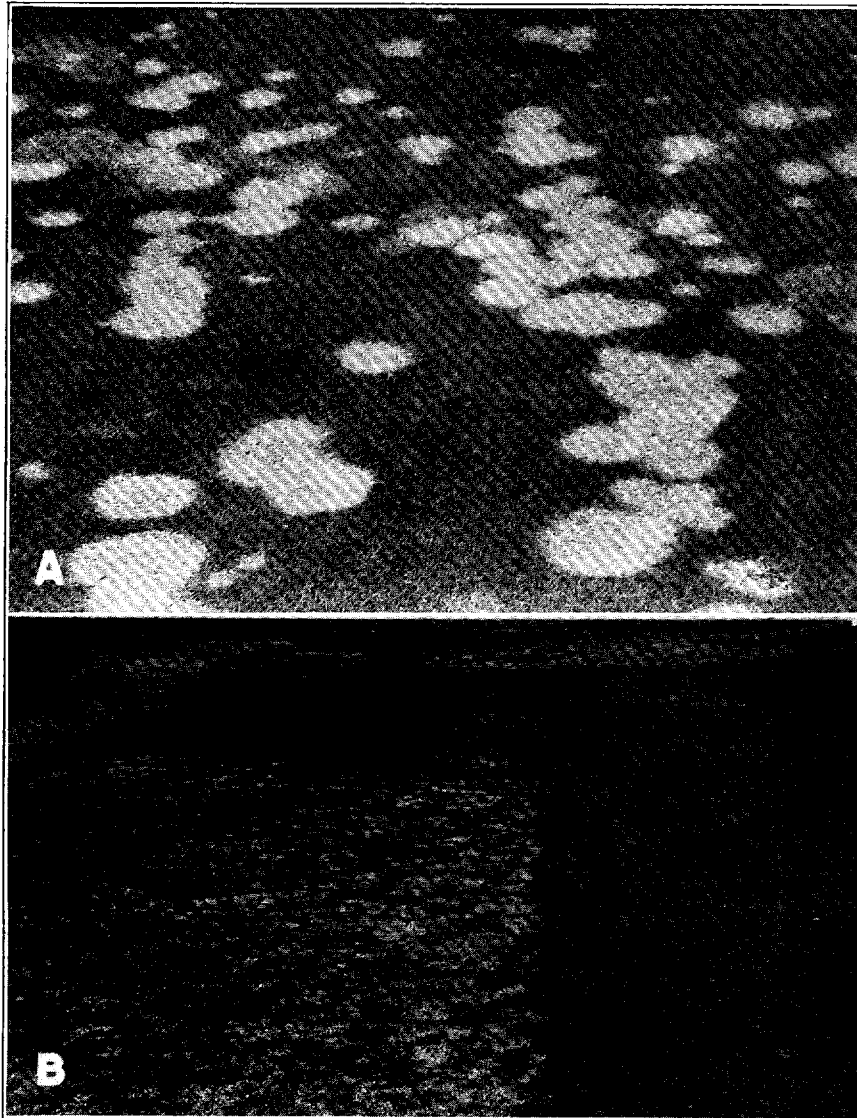


FIG. 1. A. Damage to green at Grand Rapids, Mich., caused by *Fusarium nivale*. The lighter areas are snowmold patches. Photographed on April 3, 1928. The grass on this green did not recover fully until midsummer. B. Plots of putting-green turf showing control of the disease with corrosive sublimate. The treated plot was laid out in the shape of an L and the diseased area on the left and in the background was nontreated. The fungicide was applied in the fall and the photograph was taken in April of the following year.

putting greens it may not be so serious enough to prevent the grass from recovering. Weeds may be a problem in the absence of competition.

The disease is not always found in the turf. It may be a few inches to a foot deep. When the grasses get together and cover the surface with a gray, the leaves have a bluish-gray color. These patches develop in the winter. When they are often covered with snow, the conditions remain long and the disease may be so abundant that

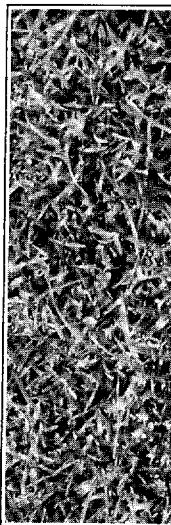


FIG. 2. Fluffy mycelium over a snowmold patch.

over the patch. Under these conditions the grass has dried and is exposed to the sunligh. The damage due to a change in color is caused by other agents are not having an abundance of grass. The grass will recover slowly. The conditions are favorable for the growth of crowns.

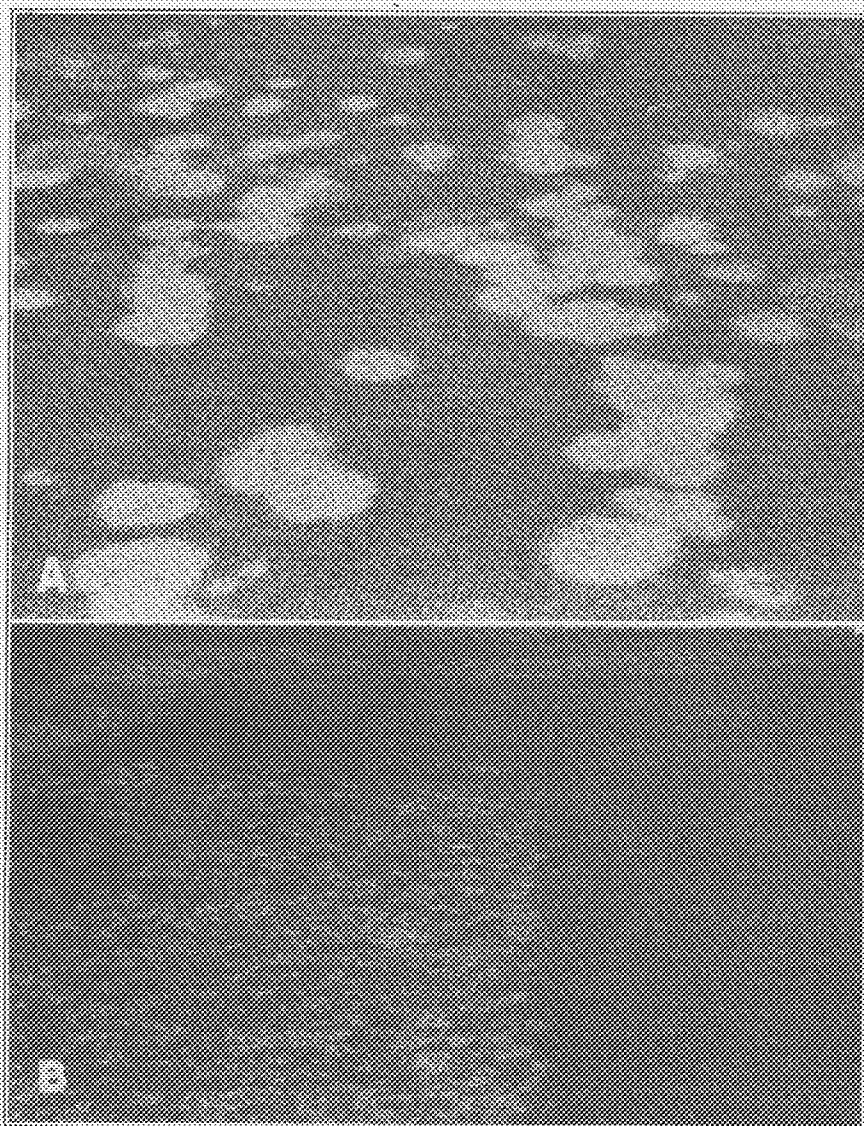


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putting greens it may not be so serious enough to prevent the grass from recovering. Weeds and other plants may take advantage of the absence of competition.

The disease is not always found in the turf. It may be a few inches to a foot deep. The grass together and cover layer may turn gray, the leaves may be killed. These patches develop in the spring. They are often covered with snow. In conditions where they remain long they may be so abundant that

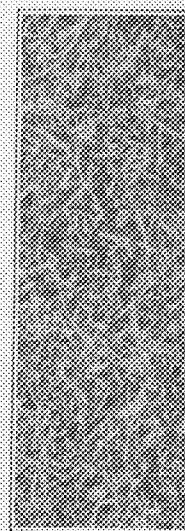


FIG. 2. Fluffy appearance of a snowmold patch.

over the patch. Under these conditions the grass has dried and is exposed to the sunlight. The damage due to a change in color is not having an abundance of grass. It will recover slowly. The conditions are favorable for the crowns.

putting greens it may kill the turf outright; but, even when the disease is not serious enough to kill the grass, it often takes a long time for the grass to recover. Weeds are apt to develop in the weakened patches because of the absence of competition from the grass.

The disease is noticeable as soon as the snow melts, when dead areas are found in the turf. These areas usually are irregularly circular, from a few inches to a foot or more in diameter and, in severe cases, may run together and cover large areas (Fig. 1, A). The patches usually are whitish gray, the leaves have a bleached appearance and, when wet, feel slimy. These patches develop under the snow while it is melting and at that stage they are often covered with an aerial mycelium (Fig. 2). When the conditions remain long favorable for its development, the aerial mycelium may be so abundant that the leaves are matted together, forming a thick layer

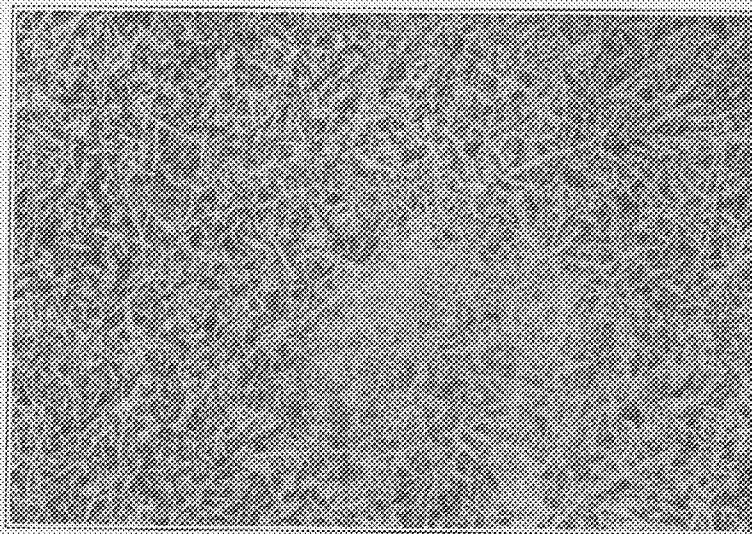


FIG. 2. Fluffy mycelium of the fungus growing over the leaves in the first stage of a snowmold patch.

over the patch. Under this layer the fungus may continue to develop after the grass has dried and the turf may be killed. When the patches are exposed to the sunlight a pinkish cast often becomes apparent on the leaves, due to a change in color of the mycelium. Light brown areas of turf killed by other agents are readily distinguished from snowmold injury. Patches not having an abundant growth of mycelium are frequently not killed but will recover slowly. The organism usually attacks only the leaves, but when conditions are favorable for a long period it spreads into the stems and crowns.

caused by *Escherichia coli*, April 2, 1933. The grass on putting-green turf showed plot was laid out in the background was nontreated. was taken in April of the

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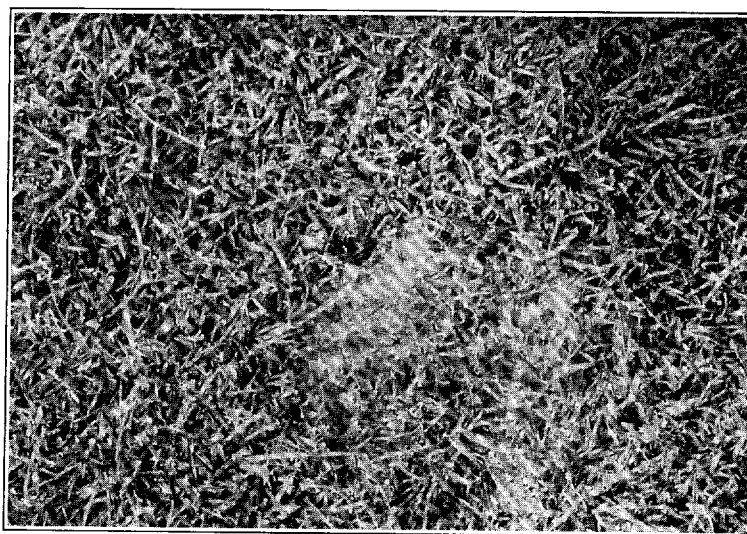


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caused by *Fusarium nivale*. April 3, 1928. The grass on of putting-green turf showed plot was laid out in the background was nontreated. was taken in April of the

The disease occurs on Kentucky bluegrass, *Poa pratensis* L., annual bluegrass, *P. annua* L., redtop, *Agrostis alba* L., creeping bent, *A. palustris* L., velvet bent, *A. canina* L., Colonial bent, *A. tenuis* Sibth., red fescue, *Festuca rubra* L., rye, *Secale* spp., wheat, *Triticum* spp., and barley, *Hordeum* spp.

CAUSAL ORGANISM

Snowmold occurring on winter grains in Europe has been shown to be due mostly to *Fusarium nivale* (Fr.) Ces. (*Calonectria graminicola* (Berk. and Brm.) Wr.) and in part to *F. culmorum* (W. G. Sm.) Sacc. Schaffnit (14) in examining material from the field found *F. nivale* in 28 out of 29 samples and *F. culmorum* in the one exception. Lindfors (8) examined at least 200 samples and found *F. minimum* (*nivale*) present in all of them. Schaffnit (14) was able to produce snowmold-like symptoms by inoculating with *F. culmorum*, *F. herbarum* (Corda) Fries, *F. didymum* Harting, *F. avenaceum* (Fr.) Sacc. and *F. lolii* Smith as well as *F. nivale* on etiolated or weakened plants. Lindfors (8) believed that *F. minimum* (*nivale*) was the most important and that the others may play a minor part in the occurrence of the disease. Atanasoff (1) inoculated pots with *Gibberella saubinetii* (Mont.) Sacc., *F. culmorum*, *F. culmorum* (W. G. Sm.) Sacc. var. *leteius* Sherb., *F. avenaceum* (Fr.) Sacc., *Helminthosporium sorokinianum* Sacc. and two other undetermined *Helminthosporium* spp. and produced conditions similar to those occurring in the field but apparently he did not make his inoculations when the temperature was near the freezing-point, the optimum for true snowmold.

Numerous inoculations have been made in moist chambers maintained at temperatures between 0° and 5° C. with *Fusarium nivale*, *F. culmorum*, *F. avenaceum*, *F. solani* Ren. and Bert., *Gibberella saubinetii*, and numerous other undetermined fungi isolated from diseased grass leaves. Of all these species only *F. nivale* proved pathogenic. Other soil fungi are often found associated with *F. nivale* in diseased patches of turf and are, at times, more conspicuous than the primary organism. In pure-culture inoculation, however, these do not produce the disease.

Cultures of *Fusarium nivale* that were used in inoculation work were isolated from diseased leaves of grass taken from patches showing symptoms of snowmold. The diseased leaves were placed in Petri dishes on water agar and transfers were made from the colonies that developed. The cultures were then grown on potato-dextrose agar. Isolations were made with material from Madison, Wisconsin, Grand Rapids, Michigan, Chicago, Illinois, and from Minneapolis and Duluth, Minnesota. Single-spore cultures were made by the dilution method after the cultures began to sporulate.

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Cultural Studies: The cultures were grown on corn-meal agar, oat-meal agar, potato-dextrose agar, and grass clippings. On corn-meal agar there was a scant aerial, colorless, and sterile mycelial growth. A very abundant mycelial growth developed on oat-meal agar and spores were produced in slimy salmon-color masses, often covering a large part of the surface of the agar. On potato-dextrose agar there was an abundant, white, fluffy, spore-bearing mycelium. On sterile grass clippings, the fungus covered each leaf with a fluffy white mycelium that in a few cases produced spores.

When the cultures were kept in darkness from the time they were isolated, there was no spore production, but when transferred to diffuse light, especially in a moist chamber, sporodochia were formed and great masses of spores developed. After the spores were once produced in light, the cultures continued to sporulate on subsequent cultures, when transfers of spores were made. Light also changes the color of the mycelium from white to a pale pink, which was demonstrated in Petri-dish and test-tube cultures and on mycelium on potted grass plants.

Schaffnit (14) found that *Fusarium nivale* grew between temperatures from 0° to 30° C., with an optimum of 22° C. Lindfors (9) and Tu (18) also found that the optimum temperature was 22° C. In the studies herein reported 3 cultures of *F. nivale*, isolated from diseased leaves from snowmold patches, were grown in constant-temperature chambers from 2 to 36° C. The cultures were grown in Petri dishes containing 10 cc. of potato-dextrose agar. Transfers of mycelium were made from young Petri-dish cultures, and the hourly rate of growth was calculated after 72 hours of growth.

Figure 3 shows the hourly growth rates at the various temperatures. The 3 cultures agree generally in their growth curve. The amount of growth at 2° C. indicates that the fungus is adapted to low temperatures. In general, the optimum appears to be about 20° C. and all of them grow as well or better at 16° as at 24°. There is a sharp drop in the curve above 24° and, although there was some growth at 32°, there was none at 36°.

Infection Experiments: The pathogenicity of the organism was proved by inoculation of potted grass plants. All of the grasses were grown in autoclaved pots and soil. The seed was treated with 1-320 Formalin for 15 minutes. The grasses were grown in the greenhouse and clipped from time to time, so that the plants were usually about 2 inches high.

The strains of the fungus were grown on sterilized grass clippings in culture tubes until the mycelium had grown throughout the clippings in the tube. A portion of the clippings was then transferred to the center of a pot of grass and held about 1½ inches above the surface of the soil by the leaves. The pots were then placed in moist chambers. Most of the inoculations were placed in a chamber kept from 0° to 5° C., since best results

were obtained at that temperature. Successful inoculations were made on creeping bent, redtop, Kentucky bluegrass, fescue, barley, wheat, rye, and oats. All of the inoculations were made on seedlings, except creeping bent, where old sod was brought into the greenhouse and potted.

In most cases infection of the leaves had taken place within 2 days after inoculation. When the amount of moisture in the chamber was decreased the infection was slight and the spread of the organism from leaf to leaf was slow. The mycelium of the organism spread quickly, when the atmosphere of the chamber was foggy, until all the leaves of the grass were covered with mycelium, as in figure 4.

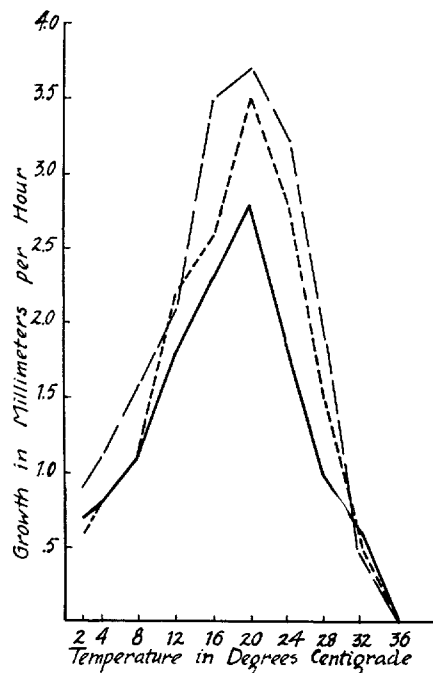


FIG. 3. Effect of temperature on the rate of growth of 3 strains of *Fusarium nivale* on potato-dextrose agar. Note their essential likeness with a rather slow rise up to 10°, then more rapid up to the optimum of about 20°, with a rapid fall above 24°. This is in contrast with the most culturable parasitic fungi, which show an optimum at about 24–30° C.

Inoculations were placed in chambers kept at temperatures from 0–5°, 5–10°, 10–15° and 15–20° C. The best results were obtained in the 0–5° chamber. The mycelium spread quickly and was abundant and fluffy. In the 5–10° chamber there was also an abundant growth of mycelium and a rapid spread of the fungus over the leaves. At 10–15° the development was much slower and the mycelium was less abundant. At 15 to 20° there

was a very small amount of mycelium and, after

Histological Studies—A greenhouse, used to determine the relation of the fungus to the grass slides, it was found that the leaf and, when a hypha entered and one or more infections opening into the intercellular spaces through the epidermal cells had collapsed and the



FIG. 4. Inoculation of grass. A. Control. B. Diseased.

mycelium developed from the leaf tissue, so that the entire length of the leaf was infected. The temperature and moisture conditions were favorable for the growth of the mycelium, the infection of the leaf surface.

The growth of the mycelium was rapid until numerous hyphae had collapsed and the fungus had become fluffy. The fungus then penetrated the leaf tissue.

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was a very small amount of infection near the inoculum; there was no aerial mycelium and, after 3 weeks, very slight spread of the organism.

Histological Studies: Material obtained from plants of Kentucky bluegrass, redtop, and creeping bent, inoculated with pure cultures in the greenhouse, was used to determine the method of penetration of the organism and the relation of the fungus and host tissue. Upon examination of prepared slides, it was found that the mycelium developed along the outside of the leaf and, when a hypha reached a stoma, it enlarged at the terminal end and one or more infecting hyphae developed down through the stomatal opening into the intercellular spaces. (Fig. 5, A). No direct penetration through the epidermal cells was observed until after the cells within the leaf had collapsed and there was an abundant development of mycelium. The



FIG. 4. Inoculation of pot culture of Kentucky bluegrass with *Fusarium nivale*. A. Control. B. Diseased plants with an abundance of aerial mycelium.

mycelium developed faster along the surface of the leaf than it did within the leaf tissue, so that new infections through stomata took place along the entire length of the leaf until it became wholly infected. When temperature and moisture conditions were not favorable for abundant aerial mycelium, the infection of the leaf was slower because less mycelium grew along the surface.

The growth of the organism in the tissue is intercellular with much branching until numerous hyphae extend in all directions. Later the cells collapse and the fungus almost fills the space occupied by the collapsed cells. The fungus then penetrates into the vessels.

It was observed that when a leaf is badly diseased, sporodochia develop through the stomata in rows. An abundant growth of mycelium at first

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quickly, when the atmos-
leaves of the grass were

was a very small amount of infection near the inoculum; there was no aerial mycelium and, after 3 weeks, very slight spread of the organism.

Histological Studies: Material obtained from plants of Kentucky bluegrass, redtop, and creeping bent, inoculated with pure cultures in the greenhouse, was used to determine the method of penetration of the organism and the relation of the fungus and host tissue. Upon examination of prepared slides, it was found that the mycelium developed along the outside of the leaf and, when a hypha reached a stoma, it enlarged at the terminal end and one or more infecting hyphae developed down through the stomatal opening into the intercellular spaces. (Fig. 5, A). No direct penetration through the epidermal cells was observed until after the cells within the leaf had collapsed and there was an abundant development of mycelium. The



FIG. 4. Inoculation of pot culture of Kentucky bluegrass with *Fusarium nivale*. A. Control. B. Diseased plants with an abundance of aerial mycelium.

mycelium developed faster along the surface of the leaf than it did within the leaf tissue, so that new infections through stomata took place along the entire length of the leaf until it became wholly infected. When temperature and moisture conditions were not favorable for abundant aerial mycelium, the infection of the leaf was slower because less mycelium grew along the surface.

The growth of the organism in the tissue is intercellular with much branching until numerous hyphae extend in all directions. Later the cells collapse and the fungus almost fills the space occupied by the collapsed cells. The fungus then penetrates into the vessels.

It was observed that when a leaf is badly diseased, sporodochia develop through the stomata in rows. An abundant growth of mycelium at first

of 2 strains of *Fusarium nivale*
a rather slow rise up to 10°,
and fall above 24°. This is in
show an optimum at about

temperatures from 0-5°,
are obtained in the 0-5°
abundant and fluffy. In
growth of mycelium and a
10-15° the development
ant. At 15 to 20° there

occurs through the stomata and later develops into sporodochia that bear great masses of spores on club-shape sporophores (Fig. 5, B). Most of the spores become detached during the preparation of the slides. In some

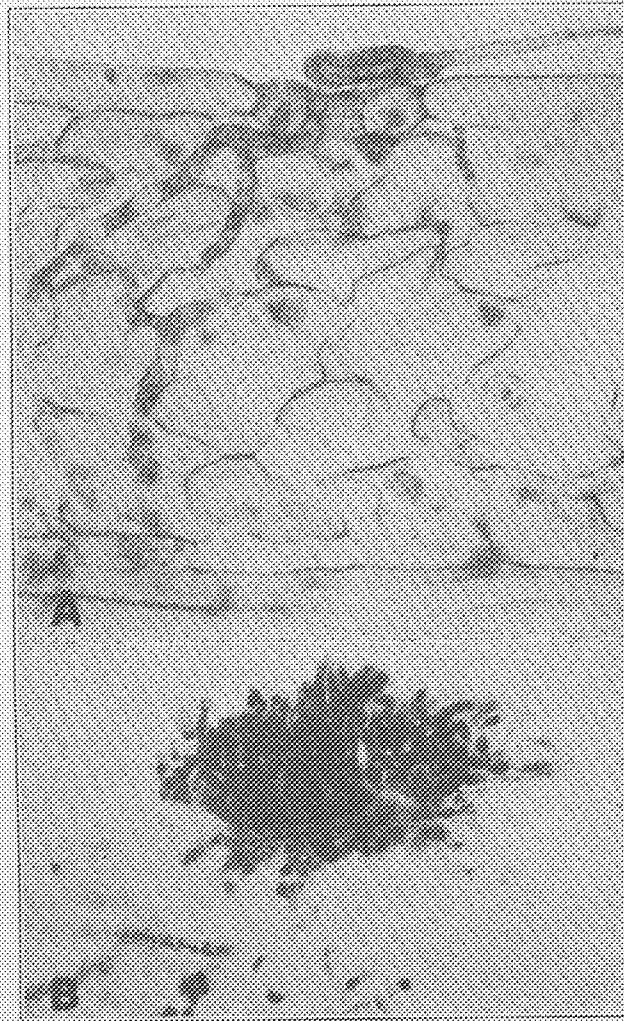


FIG. 5. A. Infection of a leaf through a stoma. Note the enlargement of the end of the infecting hypha and the intercellular course of the invading hyphae. B. Sporodochium as it occurs on a stoma. The guard cell of the stoma is located just below the sporodochium.

cases the sporodochia become so large that they cover a considerable surface of the leaf, so that 2 or 3 stomata are involved. After the leaf is badly

diseased, penetration is nearly all of the parts intact.

INFLUENCE

Weather conditions influence the disease. Unger (19) reports that when snow fell on no disease was very severe on lawns covered with a snow cover and a slow

Soraner (15, 16) reports that in winters and stopped the disease formed between the leaves. There was a saturated atmosphere and the development of the disease

Hiltner and Ihssen (17) report that the snow melted slowly and the disease was worse after the snow abundant as the snow

In Minneapolis, Minn., the ground was frozen, so that putting greens the next year in Rapids, Mich., where the disease was apparent

Deep snow, however, does not stop the disease. During the winter some of the courses were covered on these greens. The disease eventually there was sufficient to note growth of the disease

Sunlight and dry weather when the snow has disappeared the mycelium and the leaf moisture is held in the leaf to injure the turf severely. Schaffnit (14) records that if or air currents come in. In turf, where the phyllosticta fungus may continue to become active and sprout these patches to break up these patches and let the disease be stopped.

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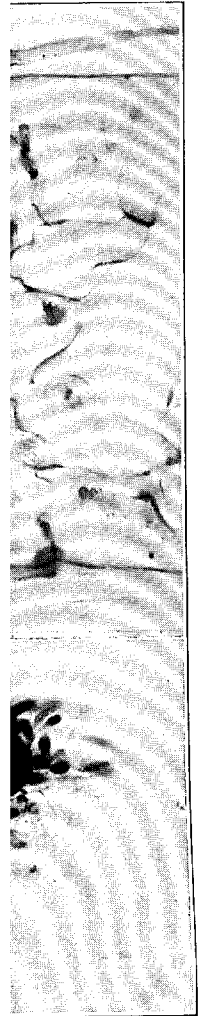
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INFLUENCE OF WEATHER ON OCCURRENCE OF DISEASE

Weather conditions play an important part in the development of the disease. Unger (19) reported that snowmold was serious after a wet fall, when snow fell on unfrozen ground. Pokorny (13) also found snowmold very severe on lawns during the spring of 1865, after a winter of continuous snow cover and a slow thaw in the spring.

Sorauer (15, 16) stated that the organism grew continually during mild winters and stopped only when it freezes. He explained that cavities were formed between the snow cover and the ground and in these cavities there was a saturated atmosphere and low temperature, which was suitable for the development of the fungus.

Hiltner and Ihssen (6) found snowmold worse on northerly slopes where the snow melted slowly in the spring. Mortenson (12) observed that the disease was worse after wet summers, when the moisture in the ground was abundant as the snow fell.

In Minneapolis, Minn., in the fall of 1927, when snow fell before the ground was frozen, severe attacks of snowmold were found on some of the putting greens the next spring. The same was true that year in Grand Rapids, Mich., where the snow melted before the end of the year and the disease was apparent in the latter part of December.

Deep snow, however, is not always necessary for the development of the disease. During the winter of 1927-28 at Madison, Wis., many greens on some of the courses were bare much of the time and snowmold was present on these greens. There was much cold and cloudy weather, and apparently there was sufficient soil moisture and atmospheric humidity to promote growth of the organism.

Sunlight and dry winds soon stop the development of the organism after the snow has disappeared. Where there has been an abundant growth of mycelium and the leaves are matted together, air and sunlight are kept out, moisture is held in the turf, and the organism continues to grow and to injure the turf severely. Hiltner and Ihssen (6), Atanasoff (1), and Schaffnit (14) record that the mycelium disappears as soon as the sunlight or air currents come in contact with it and the plants then begin to recover. In turf, where the plants are crowded, sunlight does not penetrate and the fungus may continue to live. Whenever a cloudy day occurs, it may again become active and spread. Greenkeepers have made a practice of brushing these patches to break the mat of leaves and mycelium. This dries the patches and lets the sunlight in, so that the development of the organism is stopped.

es were recorded under the
 bulb was placed under a cov-
 eried under a thick layer of
 tant at 32° F., although the
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 here the thermograph bulb
 . When snow was present,
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ON OCCURRENCE OF DISEASE

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It has been the practice of some greenkeepers, especially in the vicinity of Minneapolis, to cover their greens with straw during the winter. In many cases this practice has led to very serious damage from snowmold. Other greenkeepers who fertilize in the fall, or have a great deal of organic matter in their top dressing, have trouble with serious attacks of the disease.

In order to determine what effect fall fertilization or straw covering would have on disease incidence, experiments were made on turf of putting greens during the winters of 1928-29 and 1929-30.

In the fall of 1928 plots of turf were laid out on a green of a golf course near Minneapolis. All combinations of corrosive sublimate, fertilizer, and straw were applied so that the experiment included plots treated with corrosive sublimate; corrosive sublimate and straw; corrosive sublimate and fertilizer; corrosive sublimate, fertilizer, and straw; fertilizer with and without straw; and straw and check plots. The use of corrosive sublimate and calomel as fungicides will be considered farther on.

The corrosive sublimate, at the rate of 3 oz. to 1000 sq. ft., was diluted with a quart of sand and broadcast over the plots. The fertilizers used were activated sludge, manufactured by the Milwaukee Sewage Disposal Commission, and ammonium sulphate. These were applied at the rate of 28 lbs. of sludge and 6½ lbs. of ammonium sulphate to 1000 sq. ft. and were also broadcast on the plots. The straw was applied Dec. 1 in a layer about 2 in. thick.

Table 1 gives the results of this experiment, the figures representing the percentage of the area killed by the disease. These percentages were determined in the spring after the straw had been removed on April 3. From

TABLE 1.—Results of field experiments on plots of putting-green turf. The figures represent the percentage of turf affected by snowmold

Materials applied	Minneapolis		Grand Rapids	
	Covered with straw	Not covered	Covered with straw	Not covered
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
Checks	100	0	50	20
Corrosive sublimate	5	0	20	2
Corrosive sublimate and fertilizer	50	0	30	10
Fertilizer	100	0	90	40
Calomel and fertilizer ...			70	20
Calomel			30	5

the table it will be noted that when no straw had been applied there was no disease and where straw was applied alone, the grass was completely killed by snowmold (Fig. 6, B). The grass was killed also where the straw and the fertilizer had both been applied. Where corrosive sublimate had been applied only 5 per cent of the area of the turf was injured by disease. In

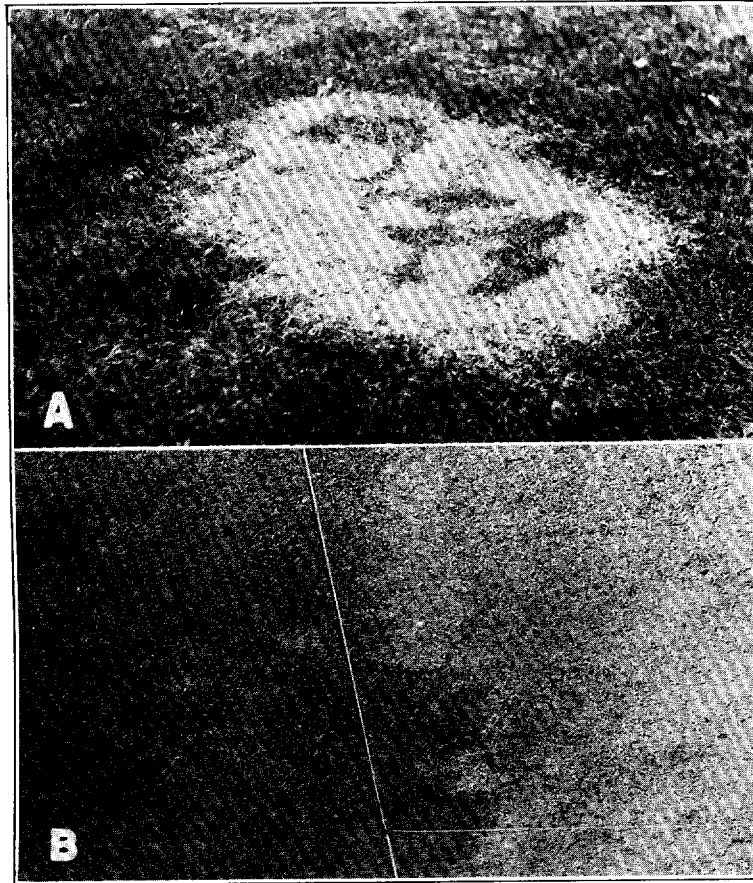


FIG. 6. A. Patch of wild creeping bent with two strains mixed together, one susceptible and the other resistant. The lighter area in the patch is the susceptible strain diseased with snowmold and the darker area is the resistant strain with no disease. B. The turf on the right of line was covered with straw during winter. The lighter area is the dead grass killed by snowmold. The darker area on the left is healthy green grass.

the plots where corrosive sublimate and fertilizer had been applied and covered with straw, 50 per cent of the turf was killed.

This experiment was repeated in the winter of 1929-30 on a golf course near Grand Rapids, Mich. All combinations of corrosive sublimate, fer-

tilizer, and straw also where calomel was sublimate and calomel wment. The fertilizer applied at the rates 1000 sq. ft.

The results of the efficiency of control by covering. There were these plots but none of previous year's experimentized and covered disease. In every case of disease and in some ing also more than d ering and application but it is much more recovers more slowly fertilized or covered efficiency of mercury ness may be much re

FIELD

Diseases of grasses by broadcasting or s able to control brown spot caused by *R. sp.* most practical of th this reason, when a c to these chemicals.

Monteith (10) m 1926-27, when he tre Wis., with corrosive treatments were effec

Since then, exper of fungicide necessa experiments, plots of Rapids and Minneap 3 oz. to 1000 sq. ft. turf to serve as chec each with one-half b broadcast over the p of sand or compost w

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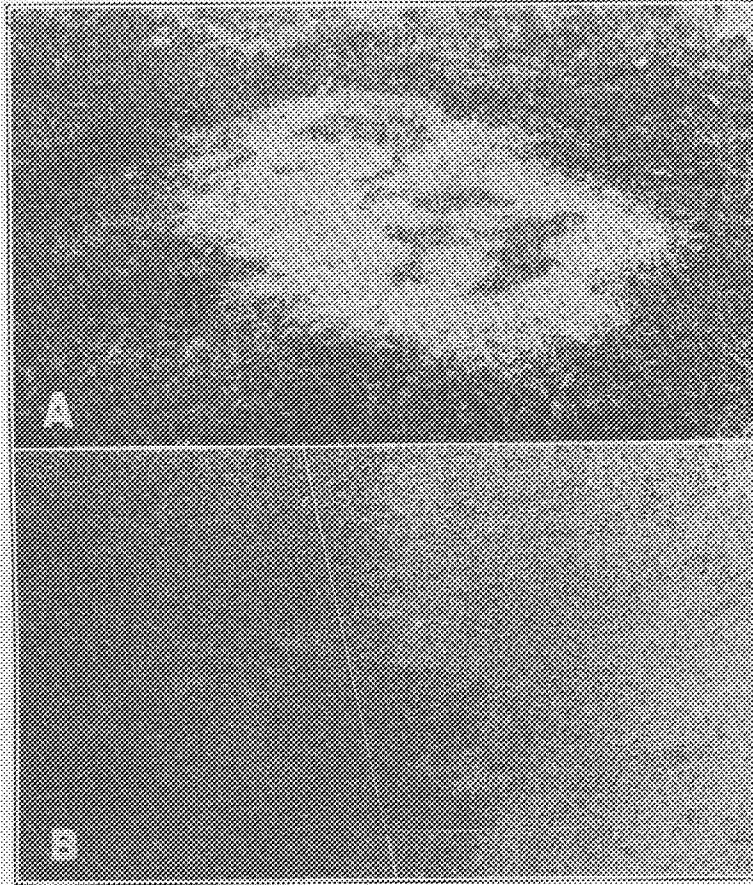


FIG. 6. A. Patch of wild creeping bent with two strains mixed together, one susceptible and the other resistant. The lighter area in the patch is the susceptible strain diseased with snowmold and the darker area is the resistant strain with no disease. B. The turf on the right of line was covered with straw during winter. The lighter area is the dead grass killed by snowmold. The darker area on the left is healthy green grass.

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tilizer, and straw also where calomel was substituted and calomel was used without fertilizer. The fertilizer was applied at the rate of 1000 sq. ft.

The results of the efficiency of control by covering. There were these plots but none of the previous year's experiments were fertilized and covered with disease. In every case of disease and in some instances also more than during and application but it is much more recovers more slowly than fertilized or covered. The efficiency of mercury treatment may be much re-

FIELD

Diseases of grasses can be controlled by broadcasting or covering. It is possible to control brown spot caused by *R. sp.* by covering. The most practical of these methods is covering. For this reason, when a disease is caused by these chemicals.

Mouteith (10) in 1926-27, when he treated turf in Wis., with corrosive sublimate and fertilizer, the treatments were effective.

Since then, experiments of fungicide necessity have been made. In experiments, plots of turf at Grand Rapids and Minneapolis were treated with 3 oz. to 1000 sq. ft. of corrosive sublimate and fertilizer to serve as check plots. The plots were each with one-half bushel of fertilizer broadcast over the plots. The plots were covered with sand or compost w-

been applied there was no grass was completely killed and also where the straw and corrosive sublimate had been was injured by disease. In

tilizer, and straw also were applied to these plots, and one series was made where calomel was substituted for corrosive sublimate. The corrosive sublimate and calomel were applied at the same rate as in the previous experiment. The fertilizers, activated sludge, and ammonium sulphate, were applied at the rates of 25 lbs. of sludge and 5 lbs. ammonium sulphate to 1000 sq. ft.

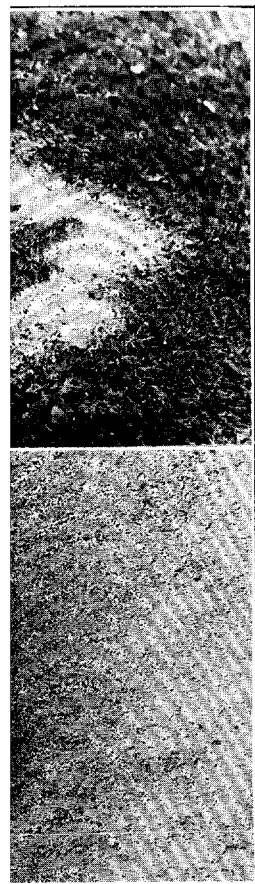
The results of this experiment, as given in table 1, show that the efficiency of control by chemicals is greatly reduced by fertilizers and straw covering. There was a more general distribution of disease over all of these plots but none of them suffered so severely as some of the areas of the previous year's experiment. The most severely injured plot was that fertilized and covered with straw, 90 per cent of which was covered with disease. In every case the covering of straw more than doubled the amount of disease and in some cases the disease was increased many times. Fertilizing also more than doubled the amount of disease. Not only do straw covering and applications of fertilizer in the fall increase the amount of disease, but it is much more severe; more of the stolons are infested and the turf recovers more slowly than when the disease occurs where the turf was not fertilized or covered with straw. The results of these experiments show the efficiency of mercury fungicides when applied alone and that this effectiveness may be much reduced by cultural practices.

FIELD EXPERIMENTS ON CONTROL MEASURES

Diseases of grasses in turf have been controlled for the last few years by broadcasting or spraying fungicides on the turf. Monteith (11) was able to control brownpatch, caused by *Rhizoctonia solani* Kühn, and dollar-spot caused by *R. sp.*, by treating the turf with mercury compounds. The most practical of these have been corrosive sublimate and calomel. For this reason, when a control for snowmold was sought, attention was turned to these chemicals.

Monteith (10) made the first preliminary tests during the winter of 1926-27, when he treated plots of turf on greens of a golf course at Madison, Wis., with corrosive sublimate at rates of 1 and 2 oz. to 1000 sq. ft. These treatments were effective in preventing snowmold in the spring of 1927.

Since then, experiments have been conducted to determine the amount of fungicide necessary to the effective control of the disease. In these experiments, plots of turf were laid out on greens of golf courses at Grand Rapids and Minneapolis. These plots were treated at the rates of 1, 2 and 3 oz. to 1000 sq. ft. The plots were separated by 2-ft. strips of nontreated turf to serve as checks. The chemicals were applied by carefully mixing each with one-half bucket of sand or fine compost and this mixture was broadcast over the plot. The checks were treated with the same amount of sand or compost without the fungicide.



strains mixed together, one susceptible patch is the susceptible strain resistant strain with no disease during winter. The lighter area on the left is healthy green grass.

lizer had been applied and killed.

of 1929-30 on a golf course of corrosive sublimate, fer-

Table 2 shows the results obtained on 4 of the experimental plots. The figures represent percentages of area of the turf affected by disease. The largest rate of application was not entirely effective in most cases. However, where the disease did occur on these plots and where it occurred on greens treated with a 3 oz. to 1000 sq. ft. rate, it was rarely severe and the turf soon recovered. The 2-oz. rate decreased the amount of the disease considerably, and here, too, the severity of the injury was lessened. The 1-oz. rate was not very effective, although it did lessen the severity of the disease to some extent. In the checks the amount of disease was not only greater but the injury to the grass was severe and the turf took longer to recover. Figure 1, B illustrates the effectiveness of control of snowmold with corrosive sublimate.

Golf courses that had been troubled with snowmold for several years have for the past few years been making a practice of treating all of their greens with either calomel or corrosive sublimate and have been successful in preventing serious attacks. Calomel and corrosive sublimate are almost equally as effective and both are used widely by greenkeepers. Some greenkeepers treat only those greens which are likely to be attacked and thus are saved the expense of treating all of their greens.

TABLE 2.—Results of field experiments on control of snowmold on putting greens on golf courses. The figures represent the percentage of diseased turf. Each series of plots was laid out on different greens

Series number	Grand Rapids		Minneapolis	
	1	2	3	4
Treatments	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
3 oz. Corrosive sublimate	5	5	0	5
3 oz. Calomel	5	20	0	5
2 oz. Corrosive sublimate	40	40	0	20
2 oz. Calomel	20	40	0	20
1 oz. Corrosive sublimate	80	60	20	40
1 oz. Calomel	40	20	40	20
Checks	90	90	80	60

VARIATION OF RESISTANCE TO DISEASE IN STRAINS OF GRASS

It has been observed that there is a difference in the susceptibility of varieties of winter grains, to attacks of *Fusarium* blight. Hiltner and Ihssen (6), Lindfors (8), and Atanasoff (1) mention this difference in resistance. The same has been observed to be true with different grasses used on golf courses.

The amount of snowmold that may occur on a golf course may be governed by several factors. It may be due to the location of the greens, that

is whether or not the turf is covered with deep drifts for long periods. Snow melts slowly in the winter and the fungus more severe attacks. The abundance of organic matter is another factor. In some cases the abundance of organic matter is another factor. In some cases the abundance of organic matter is another factor. In some cases the abundance of organic matter is another factor.

The resistance of different strains of grass to disease on a golf course varies. Some strains of creeping bentgrass are probably resistant. The disease is often severely damaged and does not recover in these plots when growing weather conditions are favorable. On courses in Grand Rapids those particular courses are those particular courses. The strain of creeping bentgrass is rarely serious enough to appear early in the spring. The seed, while the others are not observed on the course. On demonstration plots are grown in turf in which are observed to be severe attacks of a spot of disease.

Metropolitan bentgrass plots, where snowmold developed on this strain named strain, found in the wild strain had 40% disease.

Fescue is susceptible to disease. The plots were planted the grass and the limiting factors in the soil.

On a fairway near the clubhouse growing together. Some plots have been attacked by snowmold of 2 strains of bentgrass. The turf was green. Figure 6

Hiltner and Ihssen (6) and on manured soil

experimental plots. The amount of disease affected by disease. The disease was active in most cases. How- ever, and where it occurred on the plots was rarely severe and the amount of the disease injury was lessened. The amount of disease was not only lessened the severity of the disease and the turf took longer to recover from the effects of control of snowmold

snowmold for several years. The results of treating all of their plots and have been successful. Fertilizers and fungicidal substances are almost always used by greenkeepers. Some greenkeepers have been attacked and thus are

of snowmold on putting greens and on diseased turf. Each series of

Minneapolis		
	3	4
Strain	Per cent	Per cent
Metropolitan	0	5
Wayzata	0	5
Wild	0	20
Colonial	0	20
Seaside	20	40
Washington	40	20
Columbia	80	60

STRAINS OF GRASS

difference in the susceptibility of the grasses to snowmold. Hiltner and Ihssen mention this difference in resistance with different grasses used

on a golf course may be governed by the location of the greens, that

is whether or not they are sheltered from sun and wind and are covered with deep drifts for long periods in the winter. On such greens the snow melts slowly in the spring and poor drainage may make attacks of the fungus more severe. The methods of culture used by the greenkeeper is another factor. If he fertilizes heavily late in the fall or supplies an abundance of organic matter, it is probable that he will be troubled with attacks of snowmold.

The resistance of the grass to snowmold also is a factor in the occurrence of disease on any particular golf course. It has been observed that some strains of creeping bent are very susceptible, while others are noticeably resistant. The Columbia type strains, which make a thin turf, are often severely damaged by numerous patches of snowmold. The turf does not recover in these patches, but must fill in from the edges of the patches when growing weather comes. This type of grass is used on several golf courses in Grand Rapids and Minneapolis, and is one of the reasons why those particular courses are troubled with snowmold. The Washington strain of creeping bent is often attacked by snowmold, but the disease is rarely serious enough to warrant resodding and usually the injury disappears early in the spring. Seaside creeping bent, which is propagated by seed, while the others are propagated by stolons, also is a susceptible strain, and when observed on golf courses it usually is severely attacked by disease. On demonstration plots in Detroit and Grand Rapids, where several grasses are grown in turf in 10' by 10' plots side-by-side, the seaside bent has been observed to be severely attacked, while Colonial bent beside it did not have a spot of disease.

Metropolitan bent is resistant to snowmold. On the demonstration plots, where snowmold has appeared on other grasses, little has developed on this strain. At Wayzata, Minn., Metropolitan and an unnamed strain, found on the golf course in 1929, were growing side-by-side. The wild strain had 4 or 5 times as much disease as the Metropolitan strain.

Fescue is susceptible and on some golf courses where fescue greens were planted the grass has been eliminated by snowmold. This is one of the limiting factors in the growing of fescue greens in this country.

On a fairway near Grand Rapids several strains of creeping bent were growing together. Some of these were in large patches and several had been attacked by snowmold. One patch was observed that had a mixture of 2 strains of bent. One of the strains was severely diseased and the other was green. Figure 6, A shows this patch of grass.

DISCUSSION

Hiltner and Ihssen (6) found snowmold worse on strong vigorous plants and on manured soils or where straw had been applied. They recom-

mended grazing the fields in the fall because it reduced the amount of leaf area. Lindfors (8) also recommended reducing the amount of leaf area by later seeding, fall grazing, or cutting. Both investigators explain the increased severity of snowmold on the assumption that larger plants give off more heat because of the greater amount of respiration. However, the temperature under the snow does not vary from the freezing-point and is not higher where there is greater leaf area or where straw has been applied. The greater amount of snowmold under those conditions may be, in part, due to the ease with which the organism can spread from leaf to leaf. When the leaves are abundant and large, the mycelium overgrows the leaves and they become matted together to form a layer over the plants. Under this layer the organism can develop as long as temperature remains low, even after the snow has disappeared.

The large amount of organic matter in putting green turf enhances the disease, and where straw is applied and kept wet by the snow cover, there is an abundance of material on which the fungus can develop saprophytically. From this substratum the mycelium of the organism can spread to the leaves of the grass plants.

The absence of serious attacks of snowmold on winter grains in this country probably is due to the winter freezes that occur before snow falls. In Europe snow falls before many frosts have occurred and before the growth of the plants has stopped. In this country these freezes stop the growth of the plants and the tissue of the leaves becomes mature. When the plants are growing actively and the vegetation is soft and succulent, there is rapid assimilation and respiration. These processes are balanced and as the tissues mature they are slowed and there is a storage of carbohydrates and a loss of water from the cells. Such mature tissue is apparently not susceptible to attacks of the disease. But when the plants are still in an active vegetative state and snow occurs, the elimination of light stops assimilation; respiration continues, so that the carbohydrate reserves are reduced and the tissues may be a better medium for the growth of the fungus. Under these conditions the plants are more susceptible to attacks of the disease. On putting greens it has been apparent that strong growth of grass in the fall encourages attacks of snowmold. This is not due to increased temperature and cannot be explained in all cases by increase in leaf tissue because grass is clipped very short on greens in the fall. Plots treated with fertilizer were cut the same height as the nontreated plots, so that the amount of leaf area was almost the same. It is probable that the greater amount of disease is due to the immaturity of the tissue of the leaves, which makes it more favorable for the development of the fungus than the more mature tissue of plants that are not growing. On putting greens, grass stimulated by fertilizers late in the fall, is not allowed to mature before snowfall, thus making it susceptible to attacks of snowmold.

Snowmold occurs on grasses in the United States on golf courses in the U. S. in the form of irregular patches in the snow is melting and the diameter and may range from whitish gray or maroon to a bleached appearance. It occurs on Kentucky bluegrass, creeping bent, velvet bent,

Snowmold on golf courses is caused by *Fusarium nivale* (F. Wr.). The organism is found on grass clippings. Spores are exposed to diffused light and are white to pink. Temperature ranges from 2 to 15° C.

Creeping bent, Kentucky bluegrass, wheat, and oats were affected. The most rapid growth is at 0 to 5° C. At 15° C. the growth is slow.

The organism was found to progress through the soil in winter and then it becomes dormant in the tissue, so that it opens so that they can be removed.

Records of temperature at about the freezing point of water show that conditions greatly influence the favored attacks of the disease, falling on unfrozen soil.

Applying fertilizer to the turf makes snowmold more serious. The greens were covered with snow.

Field experiments showed that covering the turf in the autumn with 3 oz. to 1,000 sq. ft. of straw and 2 oz. to 1,000 sq. ft. of manure.

It was found that

SUMMARY

Snowmold occurs on winter cereals in northern Europe and on turf grasses in the United States and Canada. It is particularly important on golf courses in the United States and Canada. The disease occurs on turf in the form of irregularly circular patches of dead grass. These appear as the snow is melting and usually are from a few inches to a foot or more in diameter and may run together to cover large areas. The patches are whitish gray or may have a pinkish tinge. Individual plants have a bleached appearance and feel slimy when wet. On golf courses the disease occurs on Kentucky bluegrass, annual bluegrass, redtop, red fescue, creeping bent, velvet bent, and Colonial bent.

Snowmold on golf courses in this country was found to be caused by *Fusarium nivale* (Fr.) Ces. (*Calonectria graminicola* (Berk. and Brm.) Wr.). The organism grows well on oat-meal and potato agar on sterile grass clippings. Spores are formed on sporodochia when the culture is exposed to diffused light. Light changes the color of the mycelium from white to pink. Temperature studies showed that the organism grew at temperatures from 2° to 32° C. with an optimum of about 20° C.

Creeping bent, Kentucky bluegrass, redtop, red fescue, barley, rye, wheat, and oats were artificially inoculated in low-temperature moist chambers. The most rapid and injurious infections took place in chambers kept at 0 to 5° C. At 15 to 20° C. infections were slight and very slow.

The organism was found to enter the leaves through the stomata. Its progress through the tissue was intercellular until the cells began to collapse and then it became intracellular. After the mycelium became abundant in the tissue, sporodochia were formed on the leaf over the stomatal openings so that they occurred in rows on the leaf.

Records of temperatures under the snow showed that the organism grew at about the freezing-point. Observations indicated that climatic conditions greatly influenced the amount of snowmold. The conditions that favored attacks of the disease were: abundant moisture in the fall; snow falling on unfrozen ground; deep snow; and a prolonged cold, wet, spring.

Applying fertilizer late in the fall was found to make attacks of snowmold more serious. Where the soil had abundant organic matter or where the greens were covered with straw there was an increase of the disease.

Field experiments showed that the disease could be controlled by treating the turf in the autumn with corrosive sublimate or calomel at the rate of 3 oz. to 1,000 sq. ft. Applications of mercury fungicide at rates of 1 and 2 oz. to 1,000 sq. ft. were only partially effective.

It was found that there was a difference in the susceptibility to the dis-

ease in the grasses used on golf courses. Strains of grass growing side by side often have very different amounts of disease.

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