Turf Diseases and Their Control

By John Monteith, Jr., and Arnold S. Dahl

The constantly rising standard of excellence in the maintenance of golf turf continually confronts the greenkeeper with new problems. Not the least of these is the problem of turf diseases, which often evidences itself so unexpectedly that the greenkeeper is for a time at a loss to understand the real nature of the difficulty with which he must cope. It is the purpose of this number of the Bulletin to present material which may be of aid to the greenkeeper in diagnosing his turf troubles, and to suggest remedies which, in the light of our present knowledge, appear to be the most practical, the safest, and the most economical. Previous results of, and reports on, the study of turf diseases have appeared in this and other publications from time to time. It is hoped that this number of the Bulletin will meet the demand for a handy reference booklet by consolidating the old and the new information available. The subject will be treated by first presenting such fundamentals of plant pathology as may aid the greenkeeper in understanding turf diseases, then by describing common methods for controlling them, and lastly by discussing in turn the diseases and suggesting remedial measures.

In presenting this material the authors are aware that in many respects the study of golf turf diseases is still in its infancy. In some cases little or nothing is known of the causes of a disease or of the treatments likely to be effective. In some cases the possibility of injury to turf from an existing disease is recognized although its actual workings can not as yet be traced. Without a doubt there are also many hitherto unrecognized diseases at work the effects of which are being attributed to an incorrect source. In this sense, therefore, our present study must be considered as only preliminary and in no way final, but it is hoped that, by this presentation of information available to date, the disease problems confronting the greenkeeper will be clarified and encouragement will be lent for further study.

Turf Diseases Existed Before the Origin of Golf

The question as to when diseases first appeared on golf course turf will probably never be settled. Among the older golfers there are many who insist that turf diseases never appeared on golf courses in the good old days. Other golfers of equally long experience testify that they observed browned areas of turf similar to the modern turf ailments when they first played the game. Some of the old cuts showing players near the cup indicate that the putting greens of early days were by no means exempt from thin and perhaps dead patches of turf which were possibly the result of diseases. It has been demonstrated many times that memory is not dependable for recording information of this type. From all information available it is entirely safe to assume that turf diseases date back much further than the origin of golf. It is quite apparent, however, that early golfers were not as critical of the turf on which they played as are the golfers of today, and consequently the question of disease was to them of little importance. The artificial conditions of growth to which turf has been subjected on golf courses have undoubtedly increased the damage caused by turf diseases. At the same time, the improvements in turf have tended to make the modern golfer far more critical and have increased the demand for turf of quality kept free at all times from any damage caused by disease or other agencies. A single small dead patch of grass on an otherwise perfect carpet of closely-clipped putting turf may be much more noticeable and arouse far more objections than would a dozen or more larger patches on a poor green of coarse grass improperly maintained.

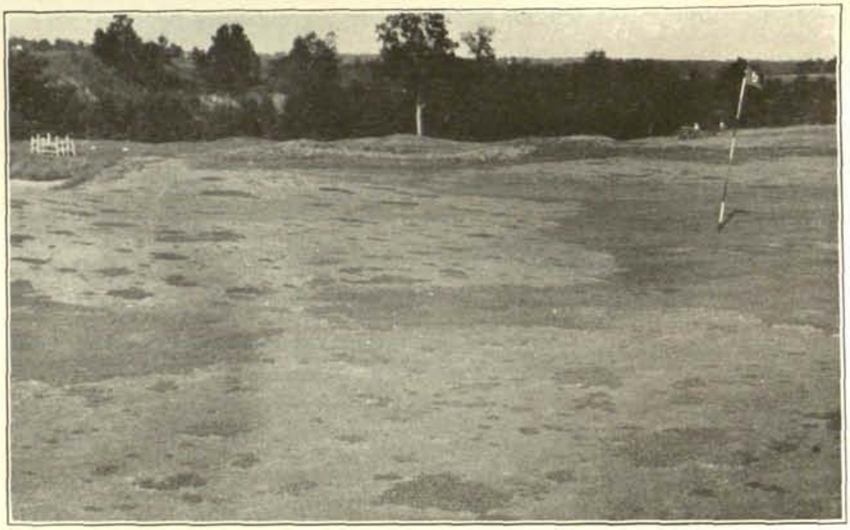

Figure 1.—An example of how turf diseases may ruin expensive putting greens. The light areas in the illustration represent the dead, browned turf resulting from different diseases. Most of the dark patches of green which remain are chiefly clover or other weeds. Such a condition necessitates replanting, results in much inconvenience to players, and adds greatly to maintenance costs.

From the practical standpoint, the discussion of whether turf diseases occurred twenty or fifty years ago on golf courses is of no importance. The important thing is that present-day golfers are constantly demanding improvement in turf and are becoming less tolerant of poor or dead patches of turf anywhere on playing areas of a golf course; consequently, to those charged with the care of turf, injury or damage at all seasons becomes a problem, and the problems of preventing injuries to turf increase as the demands of the golfers make it necessary to impose more artificial and exacting cultural methods.

We First Hear of "Brown Patch" in 1914

The modern interest in turf diseases seems to trace back to the definite recognition of a disease in the turf garden of Fred W. Taylor at his home in Philadelphia in 1914. In 1915, from browned patches of turf, a fungus was isolated which later was proved to be the cause of this injury. From that time there has been a constantly increasing interest in turf ailments of all kinds.

The disease recognized on turf in 1914 and 1915 was given the descriptive name "brown patch" which led to much confusion. Another disease was later recognized which was designated "small brown patch." Any casual student of turf knows that when turf grasses are killed by any means they usually turn to some shade of brown; therefore, if a sufficient percentage of grass is killed in an area it is likely to form a browned patch. Consequently a great many injuries which produced browned patches of turf have been designated "brown patch" without recognizing that the term was intended to apply to two definite injuries. The designations "large brown patch" and "small brown patch" have proved unsatisfactory in view of the fact that size of the affected area is not the important characteristic in diagnosing these diseases. With the more general recognition of the limitations of these two names there has resulted less confusion. Many individuals who do not keep well informed on these questions are still confused by these two misleading descriptive common names. In order to minimize this confusion the Green Section recommends that the designation of size be omitted from the name "large brown patch" and that the disease hereafter be designated simply by the compound word brownpatch. Further, that the name "small brown patch" be discontinued and replaced by dollarspot, which has already been applied to this disease. These small changes may avoid some confusion. It is well recognized, however, that unless fundamental principles are well understood, mere changes of names do not avoid misconception and futile arguments.

Basic Principles Must First Be Understood

In order to understand turf diseases and to be in a position to treat them intelligently one should have an understanding of some of the basic principles of plant growth and the manner in which diseases develop. One frequently finds injured turf on golf courses being treated with expensive fungicides in an attempt to check a loss due to chemical injury, poor drainage, or some factor other than a fungus. Such treatments are not only wasteful but often they actually aggravate conditions and result in still greater loss. In other instances, elaborate sprinkling systems have been installed which, by careless use, have resulted in great loss of turf, and, instead of correcting the misuse of water, expensive applications of fungicides have been made. If any careful observer understands some of the fundamental factors which at one and the same time influence the growth of grass and encourage the growth of fungi, he is better able to understand why it is that disease develops at certain times on one green and not on the rest of the course, and why a certain treatment will work under a certain set of conditions and not under others. For these reasons there is included in this number of the Bulletin a brief discussion of fundamental factors affecting plant diseases and their treatments.

PARASITIC DISEASES

For centuries botanists have recognized the existence of two distinct groups of plants, (1) those which are green or contain green material and (2) those which do not contain green material. This latter class includes the fungi and bacteria, and to them can be traced a host of diseases which destroy the vegetation on which man and beast depend for sustenance, as well as many serious ailments which arise to afflict man and beast directly.

Plants which contain green material are self-supporting and those which do not contain green material are dependent. The former, through the agency of light, are able to build up organic food from comparatively simple inorganic chemical compounds. They are the only living things which have this ability. The green matter in these plants is chlorophyll. All animals, and all plants of the second group, must use as food the organic materials originally built up by green plants. These dependent plants (those without chlorophyll) do not require light for their development and are thus able to live in the soil or within the tissues of plants and animals.

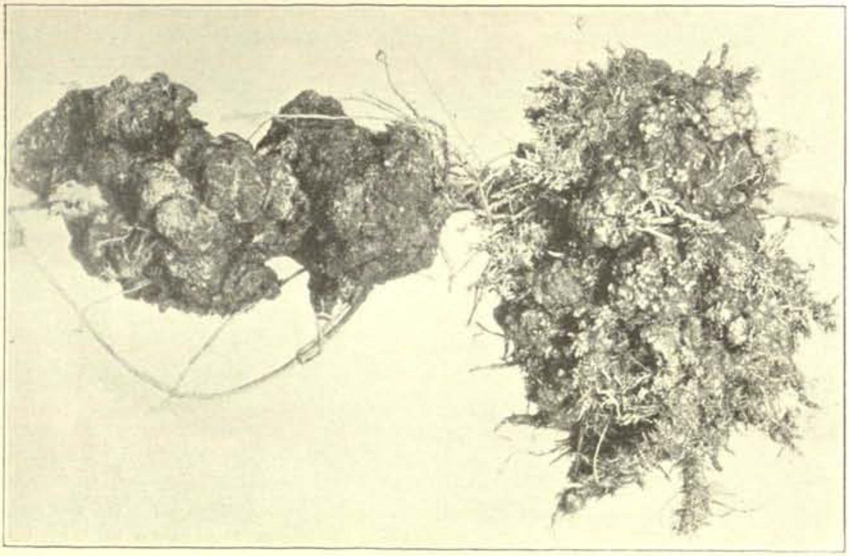

Figure 2.—Root of a willow tree diseased with crown gall and hairy root. This is an example of plant diseases caused by bacteria. Although the parasitic diseases of turf are mostly caused by fungi, there is a long list of diseases of both animals and plants caused by bacteria. In the case here illustrated, the root of the willow tree grew near the surface of a tee and probably became injured by mowers or by spikes on the shoes of players. The wounds thus made became infected with bacteria, and the root, in response, produced this abnormal growth, which pushed the sod up until the mowers scalped the turf. To save the turf the gall and hairy root had to be dug out.

The organic food built up by green plants is partially decomposed in the process of being utilized by certain animals and by those plants which do not contain chlorophyll. Still other animals and plants utilize this partially-decomposed organic matter, decomposing it still further, until it finally reaches the state of simple inorganic chemicals. This cycle, in which inorganic compounds are first manufactured into organic food by green plants, and then decomposed to their original state by animals and non-chlorophyll-bearing plants, mostly bacteria and fungi, is continuous in nature.

Included within the group of fungi are parasitic and nonparasitic plants of wide range in size and form. The group includes the toadstools, mushrooms, puffballs, molds, yeasts, mildews, rusts, smuts, and many others. Many of them first develop in the soil as threadlike filaments which absorb the organic matter in the soil. The aggregation of threadlike filaments is known as the mycelium of the fungus. Some fungi develop fruiting structures of more or less definite form which are visible to the naked eye. Familiar examples are the umbrellalike structures of mushrooms and toadstools. The filaments in the mycelium are microscopic in size, usually becoming visible to the naked eye only when large numbers of them are massed together. The great majority of fungi do not form conspicuous fruiting bodies as do the mushrooms and are seldom seen except by the trained observer.

How Parasitic Fungi Operate

While most of the bacteria and fungi live on dead organic material, some are able to use living organic material for food. In the latter case they are said to be parasitic on the plant or animal (host) of which the living material is a part. In some cases the organisms which cause diseases in plants and animals seem able to survive only within the living tissues of the host. In the majority of cases, however, the organisms which cause diseases can survive for long periods on dead organic material, becoming parasitic and thus of pathological significance only when they attack the tissues of animals or plants. Animal diseases, including those of man, are, in most cases, caused by bacteria. There are a few cases in which human diseases are caused by fungi, such as ringworm and athlete's foot. In the plant world, although there are a few instances of serious bacterial disorders, by far the majority of the parasitic diseases are caused by fungi. The parasitic diseases of turf described in this number of the Bulletin are all caused by fungi.

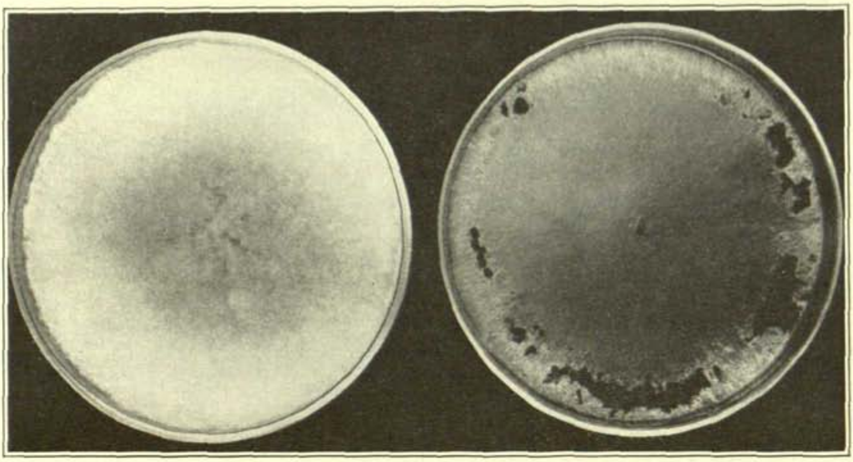

Figure 3.—Pure cultures of the fungi causing dollarspot (left) and brownpatch (right). These glass dishes contain a thin layer of sterilized food material over which the fungus has been allowed to grow. The dollarspot fungus, it will be noticed, is characterized by a fluffy growth, as compared with the flat spreading habit of growth of the brownpatch fungus. The black masses seen near the edge of the dish on the right are sclerotia (see Figure 4).

The majority of parasitic organisms live for the most part in the soil and attack plants only when conditions are favorable, at which time the filaments of the fungi penetrate the plant tissues. In general each fungus causes a characteristic type of lesion on its particular host. The part of the plant that is penetrated differs with the species of host plants, as well as with the attacking parasites. The fungi may attack the leaves, stems, roots, buds, flowers, or fruits. A single leaf may be attacked by more than one species of fungus at the same time and may be injured by a leafspot, a netblotch, and a stripe. In some cases the filaments penetrate directly through the epidermis or outer skin of the plant; in other cases they penetrate only through natural openings, such as the pores in the leaf; in still other cases entry is through wounds made by insects or by some accidental means.

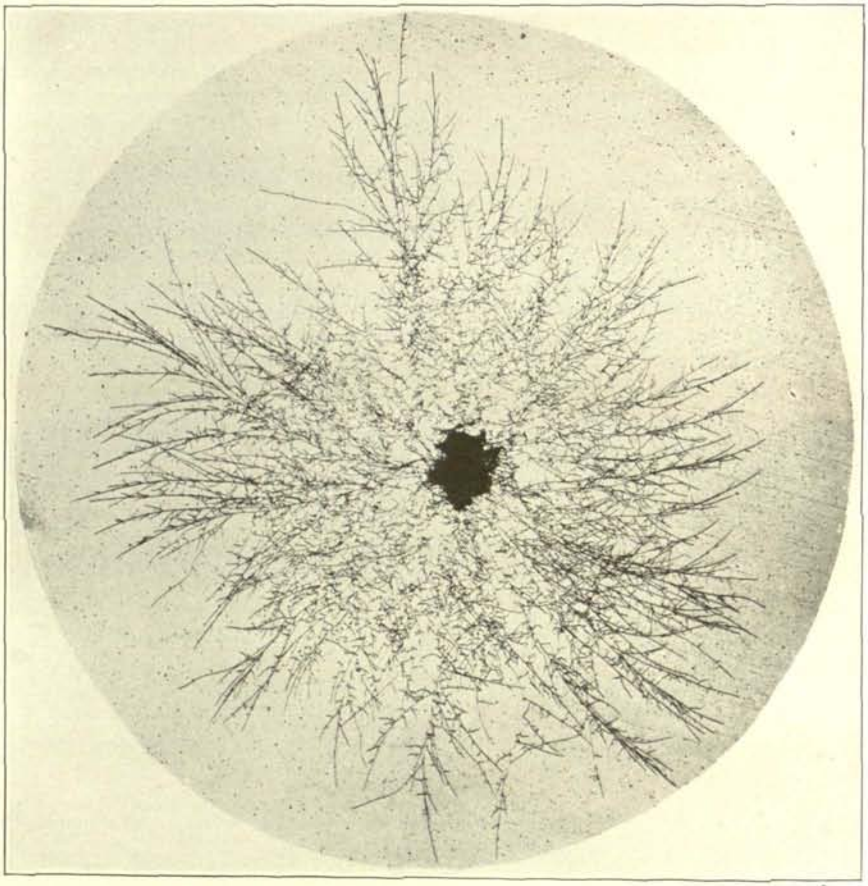

Figure 4.—Brownpatch fungus (Rhizoctonia solani) growing on culture medium (magnified 10 times). The black spot in the center is the sclerotium (see also Figure 3); surrounding it is the expanse of threadlike mycelium. Sclerotia serve to perpetuate a fungus during periods of drought or other unfavorable conditions likely to kill the delicate mycelium. Like seeds of higher plants, they send out new shoots as soon as conditions become again favorable.

Once the organism has entered its host plant the filaments grow into the interior parts of the plant and begin to absorb the organic nutrients contained in the plant cells. After the cell contents have been absorbed, the cell collapses and in most cases turns brown. In some cases a whole leaf may be almost filled with the filaments before the cells collapse, while in others the infection is localized in a small area of the leaf. In cases where the roots are attacked and killed they are no longer able to function in supplying water and food and the rest of the plant dies.

The manner in which parasites grow through a plant differs with the organism. In the case of smut on Kentucky bluegrass the fungus grows throughout all parts of its host; in other diseases, such as the

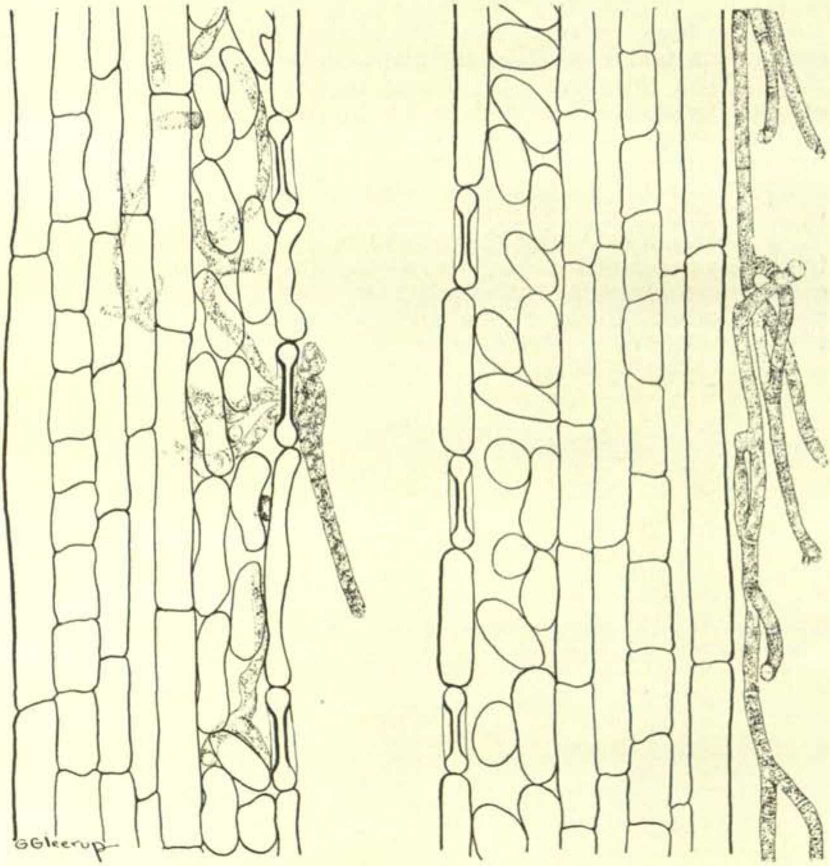

Figure 5.—How the fungus of brownpatch attacks a blade of grass. This drawing was made with the aid of a microscope at a magnification of 375 times, from very thin sections cut lengthwise through blades of grass over which the fungus was growing. The cells making up the grass blade are simply outlined, while the tubular threadlike mycelium of the fungus is represented as dark stippled strands in the drawing. On the right is shown a healthy grass blade with the fungus still entirely on the outside. In the case of the blade at the left the fungus has penetrated through one of the "pores" in the epidermis (outer skin) and has spread among the cells of the blade. By comparing the individual cells of this blade with those of the healthy blade at the right it will be seen that some cells of the former are beginning to collapse; especially noticeable is the case of the cell just above the point where the fungus entered the leaf. After the leaf is thus invaded by the fungus, the cells gradually break down, causing the leaf to shrivel and turn brown. When the fungus has penetrated a blade as here shown, no control measure is known which will restore the blade. Methods of control are based on checking the development of the fungus and following this by stimulating the grass to replace injured blades with new ones. As the sections are magnified about 375 times, the actual size of each of the sections represented was approximately 1/250 of an inch thick and 1/88 of an inch long.

zonate eyespot, the organism attacks only the leaf, where it grows very slowly through the tissue and its injury ordinarily occurs in rather small spots, although in severe cases the plants may be defoliated by the fungus spreading over the surface of the leaves.

The Workings of Fungi Are Traced in the Laboratory

It has been systematically proved that many plant diseases are caused by actual invasion of the plant tissues by parasitic organisms. To establish this proof, the causal organism is isolated from the affected tissues. This is done by preparing a sterile gelatinous nutrient material, which is placed in sterile glass tubes and flat, covered dishes. The diseased tissue of the plant is placed on this nutrient material in the dishes. When the fungus has grown out of the diseased tissue onto the nutrient material, or medium, small pieces of the medium on which the fungus is growing are transferred to the sterile tubes with a sterile needle in such a way that only a single organism will be growing in each tube. These tubes will then contain pure cultures. Pieces of the organism from pure cultures can be transferred to other sterile tubes or dishes containing nutrient ma-

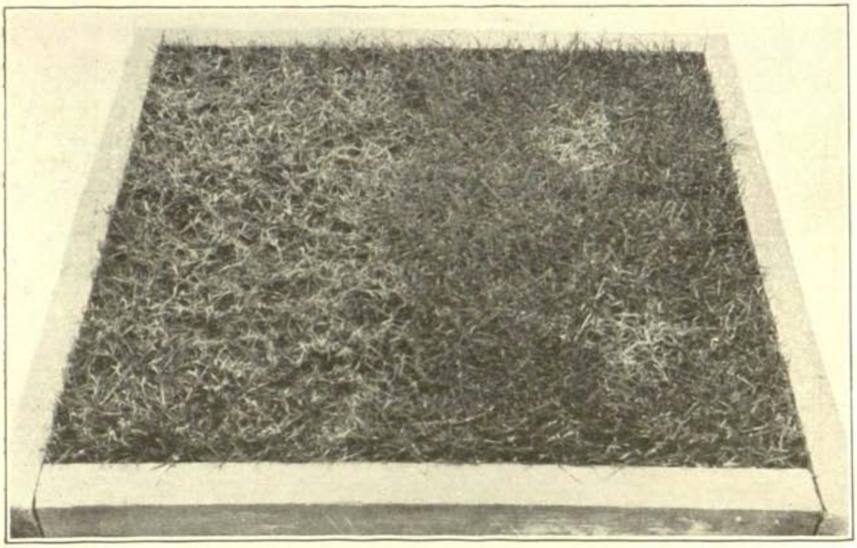

Figure 6.—Creeping bent artificially inoculated with fungi of brownpatch (left) and dollarspot (right), in greenhouse experimental work. In producing the inoculation of the grass, pieces of dollarspot fungus were taken from a culture dish such as shown in Figure 3 and deposited in two places on the grass in the right half of the flat; similarly pieces of brownpatch fungus were deposited in corresponding positions on the grass in the left half. The flat was then placed in a moist enclosure where "dew" was allowed to settle on the grass. The pieces of fungus deposited on the grass immediately started growth, infecting the grass blades. When the brownpatch fungus, spreading from the two inoculated points on the left, had covered half of the grass, the flat was removed to a drier atmosphere. As soon as the dew evaporated, the affected grass blades shriveled and turned brown, resulting in the light areas seen in the illustration. Although the inoculation of the two different disease fungi were made simultaneously, the dollarspot fungus resulted in its characteristic limited area of infection, as contrasted with the extended area of the brownpatch. Compare this with the disease as it occurs naturally (figures 23 and 24).

terial. Fungi can thus be kept in cultivation as easily as strains of creeping bent can be maintained by successive plantings.

Although the fact that an organism is always associated with certain symptoms is one point of evidence that it is causing the disease, yet this alone can not be accepted as proof. Therefore, after the organism has been found associated with a disease and has been grown in pure culture it is placed on healthy plants under conditions favorable for infection. When the symptoms of the disease appear on the plants thus inoculated, the organism is again isolated. The pure culture from the original infection is then compared with the pure culture from the artificially-innoculated plants. If they are the

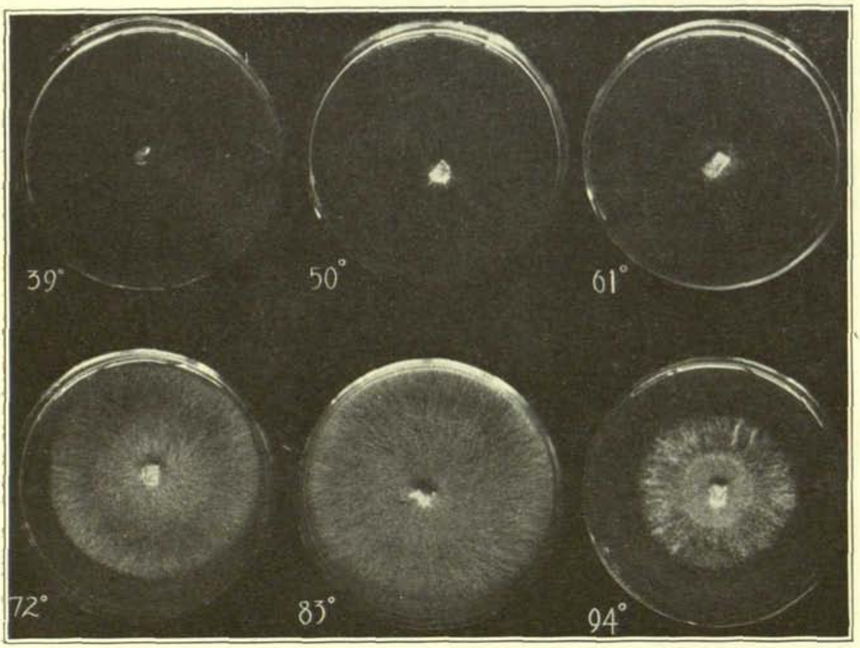

Figure 7.—Effect of temperature on the growth of the brownpatch fungus. In each of these glass dishes was placed an equal amount of food (culture medium) for the fungus. A piece of material on which the fungus was growing was then placed in the center of the dish, after which each was kept constantly at the temperature indicated (Fahrenheit). It will be noticed at 39 degrees no growth occurred and very little at 50 and at 61 degrees. The most rapid growth was at 83 degrees. In applying this to field conditions it should be remembered that the fungus usually develops during the night; so these temperatures are to be considered in terms of night averages rather than maximum day temperatures.

same it is proof that the organism in culture is the parasite that is invading the plant and causing the symptoms of the disease.

When a parasitic organism is isolated and grown in culture, it is studied in detail and observations are made of all its characteristics of growth under various conditions of temperature, moisture, reaction (degree of acidity or alkalinity), and nutriment. It is then minutely described and named. In order to avoid confusion, Latin names are used so that they will be the same in every country regardless of the language. In the animal and vegetable kingdoms there are hundreds of thousands of organisms which have thus been named, each differing in some important detail. A certain name applies only to an individual species of animal or plant, and is retained continually in the form applied when the species was first scientifically described.

Differences, however, are found to occur between individuals in certain species of fungi in the same manner as differences are found

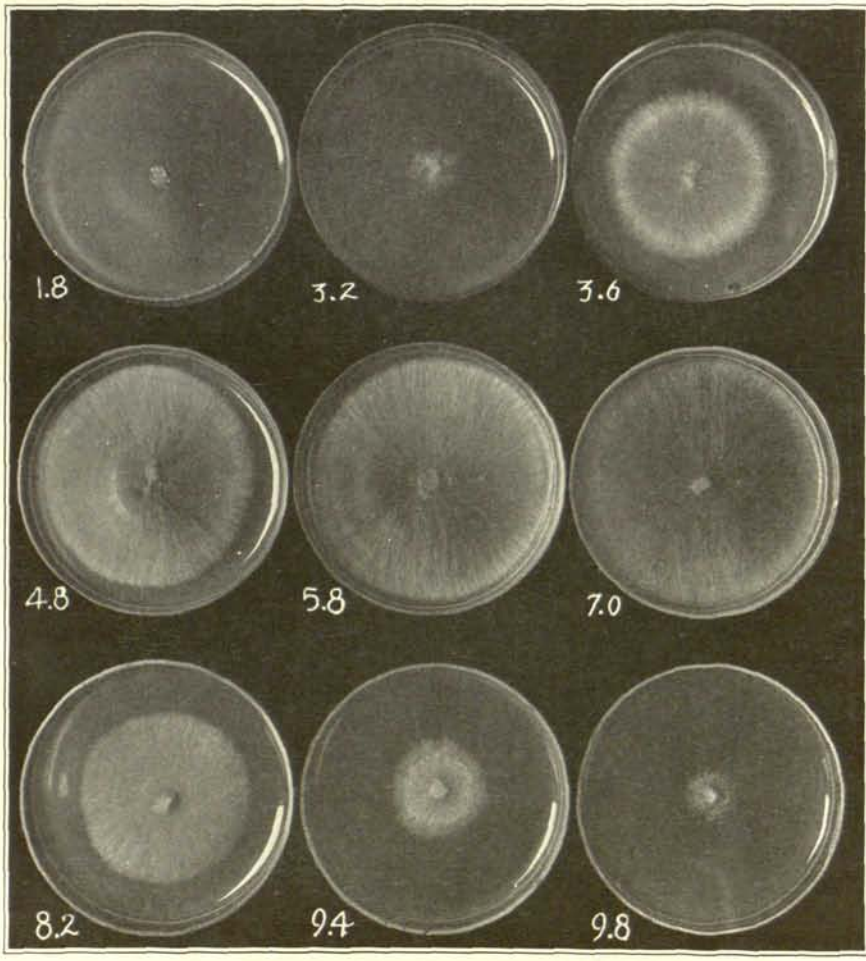

Figure 8.—Effect of acidity on the growth of the brownpatch fungus. In these nine dishes the growth of equal amounts of culture medium was started simultaneously. The growth was continued under uniform conditions except as regards the acidity of the mediums. The different degrees of acidity are shown by the pH readings beneath the dishes. A pH of 7 (right on center row) is neutral. The greater the degree of acidity, the smaller the figure below 7; those above 7 are alkaline. The most rapid growth, it will be noticed, occurred with the slightly acid or neutral mediums. The disease can not be controlled by modifying the soil reaction since this fungus has a wider range of acidity and alkalinity than the bent grasses, and the optimum growth of both fungus and bent grasses occurs at approximately the same degree of acidity.

to occur between strains of creeping bent grass. Just as differences in habit of growth, color of spores, or other major features serve to distinguish the species within a given genus, so differences in minor features within a given species serve to differentiate the individuals into strains. Thus while two strains of a fungus may be exactly alike in minute description, one may be only slightly parasitic while the other may be aggressively parasitic. In brownpatch wide differences in parasitism occur between the strains of the causal fungus, *Rhizoctonia solani*.

Environment Is an Important Factor in the Development of Disease

The importance of environment as a factor in the occurrence and severity of diseases can hardly be overestimated, since both the parasites and the host plants respond directly to conditions of environment. The fungus parasites have, for example, individual reactions to temperature. Nearly all fungi have a definite point below which they will not grow, known as the minimum temperature; a point at which they make their best growth, or the optimum temperature; and a point above which they will not grow, or the maximum temperature. The host plant also responds to changes in temperature, but its critical points of minimum, optimum, and maximum temperature may be quite different from those of the parasite. When the optimum temperature for a particular fungus is much higher than the optimum temperature for the host plant, and a temperature is reached which is favorable for the parasite but unfavorable for the host, the parasite grows abundantly, the resistance of the host may be decreased, and infection may occur.

Fungi likewise have optimum requirements as regards water, light, food, soil, and other environmental conditions which promote a rapid development of the organism. The host plants also respond to these same environmental conditions, and the resulting changes in growth help to determine in large part whether or not a host plant will be resistant to attacks of organisms in close proximity that are ready to attack.

Some Fungi Attack Many Plants

Some fungi are natural inhabitants of the soil, occurring widely distributed under widely varying environmental conditions, and are able to attack many different kinds of plants. The brownpatch fungus, *Rhizoctonia solani*, is one of these, attacking nearly 200 different species of plants. To some plants it may cause only slight injury, while to others it may cause death. It is one of the most common enemies of the potato. Species of Fusarium and Pythium are other examples of fungi capable of attacking a wide variety of plants. On the other hand, some fungi are selective in the plants they attack, a good example of this latter class being the smuts. Some species of smut fungus will attack only a single species of plant, as in the case of the onion smut, the wheat smut, and the corn smut.

NONPARASITIC DISEASES

Plants have certain fundamental requirements without which they can not live. These requirements include food, moisture, favorable temperature, light, and air. When any one of these factors is deficient or in excess the plant is unable to make normal growth, and if the extremes are too great the plant may die. Injuries thus caused are known as nonparasitic, or physiological, diseases.

Plants use simple materials which they absorb from the air or soil—carbon dioxide from the air and other necessary materials from the soil. Nitrogen, phosphorus, potash, and calcium are the most important of the latter from the fertilizer standpoint, since they are the elements in which soils are most frequently deficient. Other elements, such as magnesium, iron, and manganese are also important. When the soil is deficient in one or more of the nutritive elements the plants suffer and can be brought back to a healthy condition only by the addition of the deficient elements. A continuous supply of nitrogen is especially important for grass, since it is necessary for abundant leaf growth which is a requisite of turf.

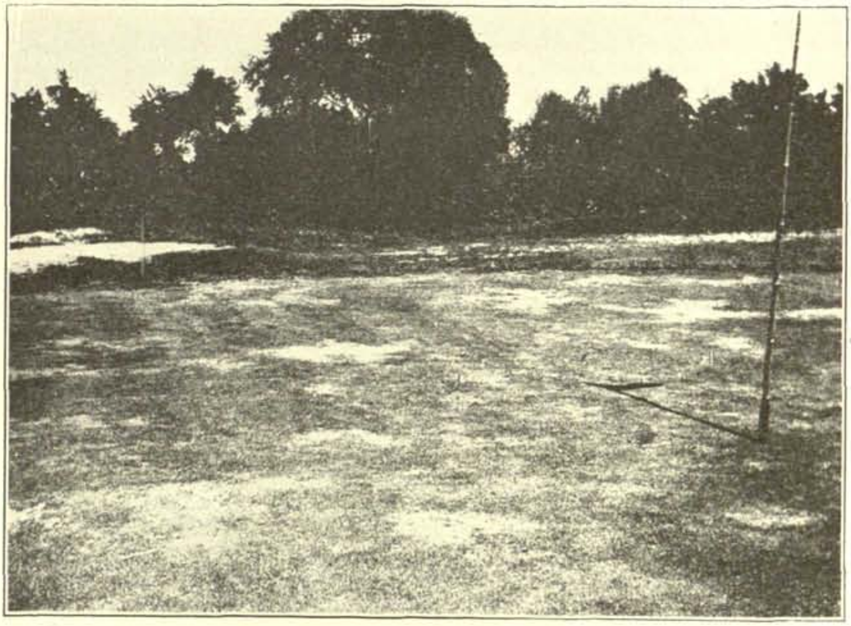

Figure 9.—An example of injury to turf by careless, uneven application of chemicals.

In order that plants may grow normally it is not only necessary to have available all the essential elements but there must be a fairly definite balance between them. If a soil contains sufficient of all the required elements to support a healthy plant and is then supplied with a great excess of any one element the favorable balance is disturbed and plant growth may be quickly checked. This balance of nutritive elements for plants may be compared in a general way with the balance needed to make a gasoline motor function properly. If there is a proper balance of spark, gas, and air the motor functions properly. Even though the supply of spark and gas, for instance, may be adequate, if an excess of air is introduced the favorable balance among the three is disturbed and the motor fails to function properly. The balancing of three factors in the gasoline motor is simple compared with the balancing of a large number of elements for plant growth. Just as temperature and other factors influence the favorable balance in the motor so temperature, rainfall, and many other conditions influence the balance in plant growth. Fortunately the soil with its various chemicals and microorganisms tends to keep the balance favorable in many cases. Under the extremely artificial soil conditions on most golf courses, however, it is easily possible to seriously upset the desired balance. For example, the more rapidly the plant absorbs nitrogen from the soil, the greater is the need for an increased supply of other elements, such as phosphorus, potash, and calcium.

Moisture also is an essential factor in the growth of plants. The limits of moisture are rather definitely fixed. When too little moisture is present in the soil the plants begin to wilt, and when there is too much moisture the roots are injured. Many crops are injured by an unbalanced water supply. The damage caused by excessive water is due to the replacing of air in the soil with water, leading to a deficiency of oxygen, which is essential for healthy root growth. Excessive water may also leach essential elements from the soil. A deficiency of water on the other hand may lead to too great a concentration of salts.

Light and a favorable temperature also are important factors in the growth of plants. Long cloudy periods and shading cause a yellowing and a weakened condition. After a period of shading, sudden exposure to bright sunlight is likely to be injurious. Changes in temperature may weaken the growth of plants. There are points above and below which plants can not live and there is an optimum temperature at which they grow best. The limits are rather wide for some plants, but near either extreme injury is apt to occur. The condition of the plant determines to a large extent the amount of injury which occurs from extreme temperatures. For instance, when a heavy frost occurs after plants have begun to grow in the spring and they are in a tender state, injury may often result.

Still other nonparasitic diseases result from direct injury to plants. An important example is burning the turf with chemicals, which frequently occurs on golf courses where insufficient care is taken in applying chemicals. Plants which are in a tender condition will not stand nearly as heavy applications of chemicals as when they are more hardy. Plants are more subject to injury from chemical burns in the summer, during the hot periods.

HISTORY OF DISEASE CONTROL

Since the dawn of history when men first noticed the occurrence of diseases in plants they have taken measures to alleviate or to prevent them. Blight and mildew were known in Biblical times. Aristotle discussed wheat rust in 350 B. C. At that time the causes of diseases were unknown and accordingly many superstitious explanations were offered. A variety of measures were taken to prevent or control diseases without any understanding of their true causes. Plant diseases were at first thought to be punishments inflicted upon the people by angry gods or malicious demons; accordingly prayers were offered and complex rituals performed to appease the gods or to frighten away the demons. These were probably the first attempts at plant-disease control.

Later treatments attempted during the early historic period were of a more practical nature. These were the results of trial-and-error methods, which in most cases were not effective. Some of these early treatments included sowing seed in the dark of the moon and "in God's name," mixing powdered lime with seed, soaking seed in salt water, running seed through burning straw, treating seed with lime and lye, and treating seed with a mixture of salt, saltpeter, lime, and wood ashes. Many of these practices were adhered to for a great many years after they had proved valueless. Even today in many parts of the world futile practices handed down through countless generations are still in use. A common example is the sowing of seed only in a particular phase of the moon, a practice based wholly upon superstition.

Only occasional practices for plant-disease control used in early days have value today and most of these are cultural practices. Some of the early practices of fertilization and crop rotation still have some value. More important is the removal of diseased plants, which is still practiced in controlling some diseases. In a diseased group of plants there is a natural selection or thinning of the stand, because the most susceptible individuals succumb first and produce no progeny. This tends toward improvement without the interference of man.

Not until the seventeenth century were concerted efforts made to control diseases by spreading various concoctions on the plants themselves, although as early as 470 B. C. Pliny had recommended the sprinkling of pure amurca of olives for prevention of plant blight. The cause of plant diseases was not understood even in the seventeenth century, when experiments were made with many mixtures of materials. Some of the mixtures contained a half-dozen or more materials, which were usually the most evil-smelling that were obtainable, the theory being that if the mixture was offensive to human beings it would also be offensive to the cause of the disease.

The following are the directions given in 1790 for making a mixture "to cure diseases, defects and injuries to plants." "Take one bushel fresh cow dung, one-half bushel lime rubbish from old buildings, one-half bushel wood ashes, one-sixteenth bushel pit or river sand. The last three are to be sifted fine before they are mixed. Then work them well together with a spade and afterward with a wooden beater until the stuff is very smooth like fine plaster used on ceilings of rooms." The mixture was made to the consistency of plaster or paint with soapsuds or urine, and after its application it was dusted with "dry powder of wood ashes mixed with the sixth part of the same quantity of burnt bones." A formula such as this seems ridiculous to us in the present knowledge of plant-disease control, but it is probably no more ridiculous than some of the theories and methods of which we occasionally hear for the control of brownpatch. During this early century, however, these experiments with mixtures and compounds were forerunners of the successful experimentation that has resulted in the control of many plant diseases.

Early in the nineteenth century the first successful chemical control measures for fungus or parasitic diseases were discovered. The use of copper sulphate (bluestone) for the treatment of cereal seeds to control smut was discovered in 1807. In 1821 sulphur was sprayed on plants to control mildew. This chemical is still used in a modified way against mildew. In 1833 lime-sulphur was first used to treat various diseases. These discoveries of chemicals to control diseases successfully stimulated a great deal of experimentation with chemicals during the last half of the nineteenth century. This increase in experimentation was also stimulated by the increased importance of plant diseases such as late blight of potato and powdery mildew on grape, occasioned by an intensification of agriculture which occurred at that time when cities were growing larger and greater food supplies were needed to supply the demands of increased population. Further impetus was added to the activity of the experimenters by the discovery in 1853 of the true cause of plant diseases, at which time proof of the parasitism of fungi was demonstrated.

About 1860 the foundations for the science of bacteriology were laid and soon afterwards the development of pure culture methods made it possible to cultivate parasitic bacteria and fungi which aided considerably in the study of disease organisms and their control. In 1869 the results of the first study of diseases were published in America, and about 1873 the subject began to be taught in American universities. The organization of a section in the United States Department of Agriculture for the study of plant diseases took place in 1885, and in 1888 the State Agricultural Stations were organized. During the time of these developments many of our common fungicides were discovered. Later, in the twentieth century, the study of plant diseases and their control with various fungicides has been continued intensively until a great many of the diseases can now be effectively controlled. During this century there has also been a study of the effects of cultural practices on plant diseases which has developed certain improvements that have greatly reduced the severity, or even the occurrence of disease. The control of plant diseases by production of resistant varieties by breeding and selection has given promising results in reducing losses from some diseases.

Plant Quarantines

Increased commerce between various parts of the world has resulted in the spread of plant diseases from one country to another. Thus the late blight of potato was introduced into Europe from South America about 1830, and caused the potato famine in Ireland in 1848. Powdery mildew on grape was introduced from the United States into France in 1845, and became so serious there that it threatened the grape-growing industry. Examples of diseases introduced into the United States from other countries are hollyhock rust from Europe in 1886, asparagus rust in 1896, white pine blister rust from Germany in 1906, and chestnut-bark disease from the Orient in 1904. It has been found that when a disease or an insect is introduced into a new country it often becomes much more serious than it was in the country where it originated. This is due to several reasons, one of which is that in the absence of their natural enemies, the organisms thrive more vigorously. The varieties of host plants in the old country are often very resistant, because of the many years of natural selection that have taken place. This was particularly the case with the American and French varieties of grape; the American varieties were resistant and the French varieties were very susceptible.

To check the spread of plant diseases and insects into the United States from other countries the plant quarantine laws were passed in 1912. These laws impose restrictions on the shipment of plants into the United States from parts of the world where serious diseases or insect pests are known to exist. All plants and plant materials are subjected to rigid inspection upon entry into the United States.