In general, leaf, stem, and fruit diseases are caused by airborne or insect-carried fungi, root diseases by soil-inhabiting species. Some vascular wilts are caused by soil fungi, some by fungi possessing insect vectors.

While there is probably no really simple host-pathogen relation, the complexity achieved in certain instances is truly impressive. Possibly the best understood instances of a complex interrelationship are to be found in the so-called heteroecious rusts. Here one is confronted with a pathogen that is an obligate parasite, having as many as five distinct spore types, and compelled to alternate from season to season between two botanically very different host species. How such a situation evolved over the past ages remains a complete mystery.

It goes almost without saying that critically accurate knowledge of the details of pathogen life cycles is essential to the development and application of effective control measures.

The attention given the fungi as causes of plant disease seems in large measure due to two further characteristics. In the first place, it is the fungus diseases of plants (by contrast with those of bacterial and virus origin) that are most easily controlled by chemical applications in the form of sprays and dusts. Added to this is the fact that fungi are responsible for a much larger number of the rapidly spreading, hence epidemic, diseases than are viruses or bacteria.

Whatever the reason, it is the sporadic diseases of this nature that bring about the greatest hardships on the individual farmer. Small wonder then that our most publicized maladies are wheat rust, apple scab, potato blight, and the like.

RUSSELL B. STEVENS *is associate professor of botany in the University of Tennessee. He obtained his doctorate at the University of Wisconsin in 1940 and served in the Army Medical Department during the Second World War. He is author with his late father of a textbook,* Disease in Plants.

Identifying a Pathogenic Fungus

William W. Diehl

From the beginning to the end of its life the health of every seed plant, wild or cultivated, is affected by fungi.

Even though a seed within a fruit or capsule may be sterile, it comes into contact with fungal spores and hyphae as soon as it is exposed to the air or is in contact with the ground. Spores are microscopic, seedlike, reproductive bodies, and hyphae are the microscopic vegative growths of fungi.

The air is literally charged with spores, and the soils of the whole earth are full of living spores and hyphae of different kinds of fungi. Most of the fungi are innocuous. Many are beneficial. But some thousands of recognizably different kinds of fungi are now known to be pathogens, or agents of disease, in plants.

Practical measures for the prevention and control of plant diseases depends in large part upon scientific knowledge of each pathogen and its role in nature. Since there are more than 100,000 recorded names of supposedly different kinds or species of fungi, the specific identification of a single specimen or culture of a fungus involves the exclusion of some 99,999 names. That is a technical problem akin in complexity and difficulty to the isolation and identification of any one out of 100,000 chemical compounds.

But the problem is not insuperable. There is a general procedure that leads the way out of the apparent chaos of more than 100,000 names.

First of all the specimen must be subjected to critical examination in order to determine any and all features that characterize it. Spores and fructifications, or spore-bearing structures, are the most significant features for diagnostic purposes.

To see the features to best advantage under the different powers of the compound microscope requires special preparation for each kind of material. The form as well as the texture of a fungal fructification, whether moldlike and fluffy or a solid structure, will determine the best method of treatment.

Most fructifications of microfungi are best viewed at first in place by reflected light with a hand lens or, better yet, a stereoscopic microscope, followed by examination under the different powers of the compound microscope of a very minute fragment mounted in water or in a staining medium.

Molds are more or less easily mounted in water or special mounting media, although they frequently require preliminary treatment with a fixing fluid to prevent a loss of spore heads, chains, or other delicately attached structures. Nevertheless, if immature stages are placed directly in the mountant, those structures that are too readily detached when mature often tend to remain in place so that their genesis is more readily observed.

If a fructification is large and opaque its anatomy can be discerned only in sections. Microtome sections made from materials imbedded in paraffin or nitrocellulose are the acme in elegance and are essential if good photomicrographic records are desired. Under ordinary circumstances, however, their preparation is too time-consuming to be justified, since for most practical purposes satisfactory sections are quickly made free-hand or by means of the freezing microtome. With moderate practice, excellent free-hand sections can be made using elder pith, carrot, or other convenient plant material as a clamp to hold a fragment firmly while slicing a number of sections among which only the best need be selected for study. If the material is too scanty to permit wastage or if the operator has not mastered the more rapid technique of free-hand sectioning, recourse may be had to the freezing microtome. Although a second-rate instrument as microtomes go, it has its advantages. Fungal structures that are too hard for easy sectioning or, after sectioning, are too impenetrable to transmitted light may usually be softened or cleared by soaking for a suitable period in some softener or clearing agent, such as a solution of potassium hydroxide or chloral hydrate. Clearing agents effectively remove fats and oils. Often after their use, structural details not otherwise evident are rendered more distinguishable, especially if they are stained. Certain mounting media, which clear and stain at one operation, are distinctly advantageous although the unstained aqueous mounts are usually satisfactory, especially so for water molds if the microscope illuminant is properly adjusted. A phase microscope is of decided advantage for living materials.

If the living specimen or culture possesses well-marked, matured spore-bearing structures, it is usually adequate for study. But if it bears no fructifications or only immature ones, they may often be produced or forced into recognizable maturity by such expedients as immersing them in water or keeping them in a moist atmosphere for a convenient period. Moist chambers are easily improvised by placing wet blotting paper under a bell jar or in a closed mason jar. It is sometimes preferable to keep specimens moist by having them wrapped in a wet towel. If there is any likelihood that the fungus requires an especially low or high temperature for maturation, that condition should be met.

Diagnostic features of many fungi are best developed through pure culture on selected artificial media in petri dishes. Standard media are particular combinations of nutrients and

agar gel, but there is a wide choice of formulas. The growth reactions of some species are characteristic on certain media and not on others. In pure culture on artificial media a species may, furthermore, present a different appearance from that in nature. Hence it may be needful to grow it upon the natural substrate to obtain the development of normal fructifications.

Having observed and interpreted the more significant morphological features, one records them, at least tentatively, by means of sketches and notes. One pays special attention to measurements.

In general, spores and spore-bearing structures are preferably measured in water mounts, because published descriptions of these features have usually included dimensions determined from material mounted in water. The recorded characters are then utilized in tracing through analytical keys of the fungi to the several classes, orders, families, and genera, and finally to a species.

There are several standard keys in general use that lead to families and genera. G. W. Martin's key to families in the very useful *Dictionary of the Fungi* (third edition, 1950), by G. C. Ainsworth and G. R. Bisby, is a simplified and modern presentation, but for keys to genera one is forced to seek elsewhere. The keys to be found in E. A. Bessey's *Morphology and Taxonomy of the Fungi* (1950) are valuable for teaching purposes, but lead to representative genera only. The key to *The Genera of Fungi* (1931), by F. E. Clements and C. L. Shear, and those to be found in Engler and Prantl's *Naturlichen Pflanzenfamilien* (1897–1900), although today somewhat outmoded, are still essential references.

When a decision is reached as to the genus to which the fungus under consideration belongs, the problem remains of finding suitable literature bearing specific descriptions. The *Guide to the Literature of the Fungi*, the last chapter in Bessey's book, lists the more useful monographs and compendia as references. Yet one cannot depend upon compendia and monographs alone. They are out of date as soon as printed. It is therefore necessary to take account of the numerous increments constantly being published —hence the need for access to well-cataloged library facilities.

Host indexes as short cuts are legitimate aids in quickly finding specific names that might apply. A pathogen may, of course, have thus far escaped record as upon the particular host, but it is likely to be recorded, if at all, on some related host. A. B. Seymour's *Host Index* (1929), based upon a complete but unpublished catalog of records up to 1924 and partly through 1926, is supplemented by the later detailed cumulative *Index of Plant Diseases in the United States* (1950) by F. Weiss and (1952, 1953) by F. Weiss and M. J. O'Brien. Various foreign lists of fungi and plant diseases, notably the anonymous *List of Common British Plant Diseases* (University Press, Cambridge, 1944) and the *Enumeratio Fungorum* (1919–1924), by C. A. J. A. Oudemans, are useful because most fungi tend to be cosmopolitan.

Actually, host indexes, like regional lists, are merely suggestions in determining identities, and one must ultimately depend on monographs, supplemented by the comparisons with herbarium specimens, including cited *fungi exsiccati*. *Fungi exsiccati* are standard replicate herbarium specimens of definite reference value, but comparisons with authentic specimens and with types constitutes a court of last resort.

Considerable information on taxonomic techniques with fungi is to be found in G. R. Bisby's *Introduction to the Taxonomy and Nomenclature of the Fungi* (1945) and in M. Langeron's *Precis de Mycologie* (1945). Whether a fungus in culture is an exact replicate of a species with ample record of pathogenicity can of course be determined only by means of culture studies with inoculation experiments in order

to reveal comparable growth reactions and host symptoms.

When the identity of the fungus seems assured, there is still the question whether its name is acceptable. Even if a specific name (epithet) has been found entirely applicable to the specimen at hand—that is, its features agree in all details with those noted in the description and it very closely resembles the type and other specimens regarded as authentic—there is always the likelihood that there may be other names (synonyms) that might apply equally well. If one or more names are found to be synonyms, a decision must be made as to which is the correct one to use, according to the current *International Code of Botanical Nomenclature* (1952). Each of the several synonyms may be valid—that is, it has been properly published—but conformity with the Code will determine which combination of generic and specific names is legitimate and, therefore, the proper choice. The present Code epitomizes the evolution in the nomenclature of fungi that began with the pioneer work of the eighteenth century.

Some persons, even specialists themselves, at times assume that the most expeditious way to get specimens or cultures identified is to refer them to individuals in other institutions. If the recipient is both competent and obliging, he is soon so overburdened with requests, many of them trivial but time consuming, that his own effectiveness in service and research is vitiated. Actually, the number of experienced mycologists equipped with laboratory, catalogs, and library facilities adequate for this kind of service in the United States, or in any other country for that matter, is limited to a few persons in a few institutions.

The taxonomist's concern, as well as his experience, is generally limited to particular genera or families. He naturally welcomes specimens and cultures that apply to his specialty; for him they are relatively easy to determine or else they challenge his mettle. Of course, no taxonomist can avoid a certain amount of drudgery; yet he should not be expected to determine the many common pathogens that ought to be more familiar to the senders. Some fairly common pathogens are often less familiar to the mycologist and can pose for him as much of a problem as any other unknown fungus. The sender is morally obligated to explain the significance and importance of his request, to supply the specimen or culture in good condition and in ample amount, as well as to accompany it with all pertinent data: Substrate, locality, date, etc. Since specimens and even cultures too often include more than one organism always possible as later contaminants, the sender should send microscopic preparations and sketches, sometimes even photographs, to avoid any possible confusion. Obviously, any materials entrusted to the mails should be so prepared that on receipt they will be in good order and not an unrecognizable mass mixed with broken glass.

As Bisby has remarked, "it is a matter of professional etiquette not to send parts of the same collection [or duplicate cultures] to be named by different experts"—to which may be added, "unless the different experts are so notified." It is almost universally considered unethical for one to publish without acknowledgment a determination provided by another. It is furthermore a convention that, lacking special agreement to the contrary, any specimens sent to another for determination become the property of the recipient for deposit in the herbarium where he is employed and that he has the right to publish at his own discretion the result of his researches upon such materials.

WILLIAM W. DIEHL *is a mycologist in the division of mycology and disease survey at the Plant Industry Station, Beltsville, Md. He has served the Department of Agriculture in Washington and at Beltsville since 1917. He is a graduate of Miami University and holds advanced degrees from Iowa State College and Harvard University.*