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# A HISTORICAL SURVEY OF BOTANICAL EPIDEMIOLOGY

## A SKETCH OF THE DEVELOPMENT OF IDEAS IN ECOLOGICAL PHYTOPATHOLOGY

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## 0. PREFACE

An institution, made up of scientists engaged in a common pursuit, has an inescapable desire to 'look over its shoulder' and to see where it came from and how far it has progressed. This survey deals mainly with epidemics caused by fungi. Its only pretence is to be the first of its kind in botanical epidemiology. It is not written by a professional historian; the authors are a participating epidemiologist and a documental biologist. The sources used are confined to published literature, in original or in quotation. 'Epidemic' and 'epidemiology' were the major, but not the only, keywords in the search for sources. Indications of inaccuracies, errors, and – most important – omissions or other comments will be welcomed.

Note: Indications between square brackets, e.g. [25] refer to quotations.

[1] 'Epidemics resemble each other in the extent of their range. Ordinary diseases attack single individuals, and if, from season or other causes, several cases occur simultaneously, they are still isolated and scattered. They never prevail at the same time among several members of a family, or among the inhabitants generally of a court, street, or town. Epidemics, on the contrary, derive their name from attacking large numbers at once.'

S. SMITH, 1866

[2] 'Epidemics are those peculiar affections which, springing up suddenly in some particular spot, spread over a certain portion of the habitable globe, and then disappear altogether.'

J. PARKIN, 1873

[3] '*Et j'ai été surpris des désordres que cause cette maladie dans les endroits qui ont le malheur d'en être affligés. Et qui ne le seroit pas en effet, de voir qu'une plante attaquée d'une maladie devient meurtrière des autres de son espèce? En avoit-on jusqu'ici remarqué de contagieuses épidémiques dans les plantes? Celle qui attaque l'oignon du safran est cependant de cette nature, puisque semblable à la peste des animaux, elle gâte les oignons voisins...*'

(And I have been surprised by the damages which this disease causes in the places that have the misfortune to be afflicted with it. And who would really fail to see that a plant attacked by a disease becomes murderous to others of its species? Has anyone until now observed contagious epidemics in plants? That which attacks the bulb of saffron is none the less of that nature, because like the pest of animals, it spoils the neighbouring bulbs...)

H. L. DUHAMEL DE MONCEAU, 1728

[4] '*Dasselbe Verhalten in der Krankheitswelt des Menschen gibt Epidemien, des Thieres Epizootien, und der Pflanze Epiphytozien, durchaus Zustände von Exacerbation irgend einer Krankheits-Species, der nach Individualität des Charakters in längeren oder kürzeren Pausen der entgegengesetzte Zustand der Ruhe folgt.*'

(The same behaviour in the world of disease among humans leads to epidemics, among animals to epizootics, and among plants to epiphytotics, generally conditions of exacerbation of some disease species, which according to individuality of character succeeds the opposite condition of rest after longer or shorter pauses.)

F. UNGER, 1833

[5] 'The field of science dealing with the relationships of the various factors which determine the frequencies and distributions of an infectious process, a disease, or a physiological state in a human community.'

KENNETH F. MAXCY

IN: W. A. N. DORLAND, 1949

# 1. INTRODUCTION

## 1.1. BOTANICAL EPIDEMIOLOGY

'Epidemiology is the science of disease in populations' (VAN DER PLANK, 1963). These populations can be humans, animals, plants, etc. Accordingly there is a medical epidemiology, a veterinary epidemiology and a botanical epidemiology (ZADOKS, 1974a), rooted in medicine, veterinary sciences and phytopathology respectively.

The term *epidemios* (ἐπιδημιος) dates from HIPPOCRATES, the revered physician of the Aegean island Cos, who lived about 460–380 B.C. (JONES, 1972). It is an adjective, meaning 'what is among the people'. The word was used for specific diseases, such as that known today as malaria.

In medicine the term epidemic appears in the title of a booklet by LEONICENUS *Libellus de epidemia*, an account of the syphilis epidemic at the end of the 15th century (CASTIGLIONI, 1947). The authors have not searched for evidence on the use of the term epidemic in the 16th, 17th and 18th centuries. The term may have been used occasionally, as is suggested by DUHAMEL's usage in 1728, and by a passage in a popularizing scientific treatise published by the Dutch medical doctor LE FRANCO VAN BERKHEY in 1771, in both cases with little explanation. In medicine, the term epidemic comes into general usage in the 19th century, either as a substantive (SMITH, 1866; PARKIN, 1873) or as an adjective (HAESER, 1845; MITCHELL, 1849). The use of the word is not yet completely consistent [1, 2]. In phytopathology, the term epidemic was used in a book title by RAMAZZINI (1691) and, independently, by DUHAMEL in a hitherto unnoticed publication dating from 1728 [3]. In 1833, UNGER introduced the German term *Epiphytozie* for an epidemic on plants, echoed by the later American term *epiphytotic* [4]. It is significant that VON MARTIUS used the word epidemic in the title of his book on potato dry rot (caused by *Fusarium* sp.), published in 1842 [38, 39]. The term reappears, with little emphasis, in some textbooks such as those by KÜHN (1858), VON TUBEUF (1895), and MARSHALL WARD (1901). The latter went into more detail in his chapter on 'The factors of an epidemic'. After 1900 the term epidemic appears more and more frequently.

The term epidemiology has been used in medicine since 1873 (PARKIN, 1873), maybe even earlier. The term is also applied to the 'vegetable creation'. It is a neologism composed of three parts, upon + people + treatise (epi + demio + logy). In 1874 a new journal was devoted to medical epidemiology, the *Allgemeine Zeitschrift für Epidemiologie* (General Journal for Epidemiology), edited in Erlangen, Germany. Epidemiology is not just the registration of epidemics. Such registrations only give a timetable of epidemics, valuable in itself, but they do not show the development of ideas. A good definition of epidemiology is given by Maxcy in *The American Illustrated Medical Dictionary* [5] (DORLAND, 1949). A similar definition is given by one of the standard textbooks on medical epidemiology (MACMAHON & PUGH, 1970). For reasons unknown, botanical epidemiology has limited its scope to infectious diseases

- [6] 'Epidemic. Widespread temporary increase in the incidence of an infectious disease.'  
PLANT PATHOLOGY COMMITTEE, 1953
- [7] 'Epidemiology. Study of the factors affecting outbreak and spread of infectious disease'.  
PLANT PATHOLOGY COMMITTEE, 1953
- [8] '*Unter eine Epidemie verstehen wir somit das gehäufte Auftreten, die örtliche Konzentration einer Infektionskrankheit innerhalb eines begrenzten Zeitintervalls*'.  
(By an epidemic we therefore understand the frequent incidence, the local concentration of an infectious disease within a limited period of time.)  
E. GÄUMANN, 1946
- [9] 'Epidemiology may be defined as the study of the laws governing the distribution of disease in the community. Epidemiological investigations, particularly in Europe and the U.S.A., have in recent years been directed increasingly towards the study of non-communicable disease'.  
J. PEMBERTON, 1963
- [10] '*Jede Epidemie verläuft eigengesetzlich, ändert ihren Charakter, schwillt an und wird bösartig, klingt ab und wird milder: sie besitzt ihr eigenes Gesicht, ihre eigene Morphologie, ihren eigenen Genius epidemicus*'.  
(Every epidemic develops according to its own rules, changes its character, expands and becomes malignant, decreases and becomes milder: it has an appearance of its own, its morphology, its own *genius epidemicus*.)  
E. GÄUMANN, 1946
- [11] '*Epidemiologie – de wetenschap van het ontstaan en verloop van ziekten*'.  
(Epidemiology – the science of the origin and course of diseases.)  
N.P.V., 1968
- [12] 'In the last 25 years there has been a progressive increase in the use of statistical methods in the solution of epidemiological problems. Those searching for aetiological factors of some of the non-infectious diseases have been quick to adapt the epidemiological method of approach profitably to their own purposes. One result is that "the epidemiology of non-infectious diseases" is a phrase in frequent use and, however painful this may be to those who prefer the limited meaning, the method of approach which the phrase suggests has undoubtedly come to stay and to play an important part in medical research'.  
I. TAYLOR & J. KNOWELDEN, 1964

only [6, 7] (PL. PATHOL. COMM., 1953), [8] (GÄUMANN, 1946; KRANZ, 1974), in contrast to medical epidemiology [9] (PEMBERTON, 1963; MACMAHON & PUGH, 1970).

In the first comprehensive treatise on botanical epidemiology, the phytopathologist GÄUMANN (1946) emphasized the individuality of each epidemic [10]. His *genius epidemicus* indicates the typical characteristics which distinguish one epidemic of a fungus on a host from another epidemic of the same fungus on the same host, and is thus very different from the older concept *genius epidemicus* mentioned in quotation [29]. GÄUMANN's view was confirmed in quantitative studies by VAN DER PLANK (1963; the 'memory factor') and ZADOKS (1971).

## 1.2. EPIDEMIOLOGY AND ETIOLOGY

Botanical epidemiology is only one of several specialisms within phytopathology, where epidemiological thinking has always been well developed. The reasons for promoting epidemiology to a specialism in its own right are complex, among them the recent ecology drive, the need for relevance in research, problems of funding (ZADOKS, 1974a). But perhaps the reorientation of scientists as a reaction to the fundamentalism in basic science ranks first. The present story of botanical epidemiology seems a necessary step to give this specialism more 'identity'. One attempt to promote its identity failed, fortunately, i.e. the plea by WHETZEL (1929) for the use of the term epiphytotic – leading to epiphytology – as the term epidemic was already in common use (BOYCE, 1948; N.P.V., 1968). A similar term is used in French, as seen in the title of the journal *Annales des Epiphyties*, which first appeared in 1913. The term *épiphyties* then also covered insect pests. At times, insect pests have been called epidemics caused by insects (e.g. MARSHALL WARD, 1901; BOURCART, 1910; BLUNCK, 1929; ESCHERICH, 1931). These should be contrasted to epidemics caused by pathogens of insects in insect populations or 'epizootics' (FRANZ, 1961), from which 'epizootiology'. Epidemiology differs from etiology, a difference obvious in medicine but not so evident in phytopathology as some book titles (ORLOB, 1964a) and formal definitions demonstrate [11] (N.P.V., 1968). Etiology is the science of the causes of disease; more precisely: disease of the individual. Of course, there is a link between etiology and epidemiology. The knowledge that an individual is diseased because of an infection by a fungus which multiplies rapidly and spreads easily can also explain disease of a number of individuals in a population.

Usually, etiology precedes epidemiology, but the epidemiology of a disease can be studied without knowledge of the causal agent(s) of that disease. Classical medical epidemiology started in this way, and much of modern medical epidemiology is directed towards diseases of unknown etiology (MACMAHON & PUGH, 1970). Such diseases may or may not be infectious (PEMBERTON, 1963;

[13] *'Indem man nämlich durch scharfe Bezeichnung aller einzelnen Erscheinungen ein entschiedenes Bild von der Krankheit entwirft, die Gelegenheits- und die prädisponierenden Ursachen kritisch erwägt, und die Verbreitung, die Dauer und Fortpflanzung des Uebels unter allgemeine Gesichtspunkte bringt, sammelt man Materialien für die Geschichte von epidemischen und endemischen Pflanzenkrankheiten, die mit der Zeit dienen mögen, den Lebensgang einer gegebenen Nutzpflanze im Grossen zu zeichnen.'*

(If one designs a distinctive picture of the disease by clear depiction of all separate phenomena, if one critically considers the circumstantial and predisposing causes, and if one looks in a general way at the distribution, duration, and propagation of the evil, then one gathers materials for the history of epidemic and endemic plant diseases, which may in time serve to show at large the life-history of a given crop plant.)

C. F. P. VON MARTIUS, 1842

[14] *'Strictly speaking, however, all that we really know is this – that where certain conditions exist, epidemics break out and spread; that where those conditions do not exist, epidemics do not break out and spread; and that where those conditions did exist, but have been removed, there-upon epidemics cease.'*

S. SMITH, 1866

[15] *'A world-wide survey such as here proposed would be very greatly facilitated by improved and extended local surveys made by the government of each country, along the general lines followed at present in Germany and in the United States. The purpose of such surveys is (1) to record the distribution of diseases of plants and their annual prevalence in each section of the country; (2) to estimate the amount of loss suffered each year, in order that the economic importance of the subject may be understood; (3) to discover the introduction into the country of new and possibly dangerous diseases, to the end that restrictive measures may be advised; (4) to study epidemics of plant diseases in relation to weather, crop distribution and other factors, and to obtain a better knowledge of the condition governing the development, spread and control of such outbreaks; (5) to gather data respecting the resistance and susceptibility of varieties to disease, for comparison of reports from different sections and correlation with climatological records; (6) to develop closer relations between phytopathologists, to build up mycological collections, to illustrate the geographical range of plant parasites, and to publish from time to time special articles or monographs on this subject.'*

W. A. ORTON, 1914

[16] *'That plant pathologists in each state be urged to make every effort to obtain information on the development of major disease hazards throughout the season, with the aid of such agencies and individuals as may be available, with a view to the issuance of timely warnings to growers and recommendations of immediate measures to be taken to check epidemics, or to lessen losses that would otherwise result.'*

WAR COMMITTEE, 1943

[17] *'Kaum jemals in der Geschichte ist während eines grossen Krieges der kommende Friede so folgerichtig vorbereitet worden wie in diesem Entscheidungskampfe des Deutschen Volkes um seine Lebensrechte. ... Die Arbeit zur Eindämmung bestimmter Gefahren – ich nenne nur Kartoffelkrebs, Kartoffelkäfer, Rübenwanze, St. José-Schildlaus – wird auf grösseren Raum ausgedehnt werden müssen.'*

(Hardly ever in history has peace been so justly prepared for during a great war as in this decisive fight of the German people for their right to exist. ... The fight to confine certain dangers – I mention only potato wart disease, Colorado beetle, beet-bug, San José scale – must be extended to a larger space.)

B. RADEMACHER, 1942



VALKENBURG, 1973; ZADOKS, 1974a). Today, there is a tendency to use epidemiological techniques in the search for etiological clues in diseases of unknown etiology [12] (TAYLOR & KNOWELDEN, 1964).

In much classical phytopathological work there was a good deal of epidemiological thinking, which had great heuristic value with respect to unknown or incompletely known etiology, with or without the use of statistics. A recent example is an epidemiological study on *Drechslera oryzae* on rice in Surinam (South America), which led to the conclusion that outbreaks of *D. oryzae* epidemics were real epidemics causing measurable crop losses, but that they should be regarded at the same time as a symptom of an economically far more important nutritional disorder (KLOMP, in press).

### 1.3. OBJECTIVES OF BOTANICAL EPIDEMIOLOGY

The objectives of botanical epidemiology are not constant in time but follow general trends of thought; rarely have they been stated explicitly.

VON MARTIUS (1842) endeavoured to bring duration and perpetuation of evil under general viewpoints with the aim of increasing our knowledge [13]. The general objective of the advancement of knowledge about the 'conditions' that promote or hamper epidemics is implicitly stated by SMITH in 1866 [14]. When the word epidemiology is interpreted extensively, all efforts made in the decades following 1890 to establish plant quarantine systems can be seen as objectives developed in that period and still valid (ANONYMUS, 1900; ORTON, 1914). Surveying techniques were developed. The study of the relation between weather and epidemics with the purpose of controlling disease became an explicit objective in the decades following 1910 [15] (ORTON, 1914; KEITT, 1959). The surveying 'for effective direction of crop protection programs' was reinforced by war emergencies [16] (WAR EMERGENCY COMMITTEE, 1942). Expansionistic dreams of warring states were translated into phytopathological benefits [17] (RADEMACHER, 1942).

In the period after World War II, timely chemical control with the help of forecasts using meteorological data became again a major objective [18] (MAYER, 1952; MOORE, 1952; MÜLLER, 1957). PAUL R. MILLER (1959) stated clearly that 'forecasting is applied epidemiology' [19]. Moreover, the demand for forecasting services based on 'meteoropathology' and epidemiology has increased in recent years [20] (DIERCKS, 1966; OORT, 1966; GROSSMANN, 1972).

Under the influence of VAN DER PLANK (1963), who brought various alternatives within one theoretical framework, and of general trends of thought within the domain of environmental protectionists and conservationists (e.g. GOLDSMITH et al., 1972) a modern viewpoint developed [21] (BUTT, 1972; ZADOKS, 1974a), in which biological control also has been given a place.

In response to the numerous questions raised by the public after the devastating 1970 epidemic of southern corn leaf blight (*Helminthosporium maydis*) in the U.S.A., the genetic vulnerability of crops was studied by a Committee on Genetic Vulnerability of Major Crops, a committee set up by the National Academy of Sciences and chaired by JAMES G. HORSFALL. The report is valuable

[18] *'Die restlose Klärung der Einwirkung der Umweltfaktoren auf das biologische Geschehen der Kulturpflanzen und ihrer Schädlinge wird in dieser neuen Epoche ein leitender Gedanke bei aller Pflanzenschutzarbeit sein müssen.'*

(The complete solution of the influence of environmental factors on the biological processes in cultivated plants and their pests will have to be a leitmotiv of all plant protection work in this new era.)

O. SCHLUMBERGER, 1949

[19] 'The forecasting of plant disease occurrence is the natural corollary of plant disease epidemiology. Through prediction and analysis forecasting both uses and contributes to epidemiological knowledge. Actually, forecasting is applied epidemiology.'

P. R. MILLER, 1959

[20] *'Überhaupt wird das etwas vernachlässigt erscheinende Gebiet der Meteoropathologie und Epidemiologie stärker in den Vordergrund gestellt werden müssen. Dabei bedarf es einer engen Zusammenarbeit mit dem amtlichen Wetterdienst der diesen Aufgaben durchaus aufgeschlossen zu sein scheint.'*

(The somewhat neglected field of meteoropathology and epidemiology must be placed on the foreground. In addition a close cooperation is necessary with the official meteorological office, which seems perfectly fitted for this task.)

R. DIERCKS, 1966

[21] '...we are now better equipped to implement the objective of epidemiology – the formulation of disease control strategy.'

D. J. BUTT, 1972

[22] 'The key lesson of 1970 is that genetic uniformity is the basis of vulnerability to crops. ...most crops are impressively uniform genetically and impressively vulnerable.'

COMMITTEE ON GENETIC VULNERABILITY, 1972

[23] 'It is clear from our study of the factors of an epidemic that one of the primary conditions which favour the spread of any disease is provided by growing any crop continuously in 'pure culture' over large areas. ... The history of all great planting enterprises teaches us that he who undertakes to cultivate any plant continuously in open culture over large areas must run the risk of epidemics.'

H. MARSHALL WARD, 1901

(see 3.7.), though the term vulnerability is more an eye-catcher than a well-defined scientific concept [22] (COMMITTEE ON GENETIC VULNERABILITY, 1972). Note that MARSHALL WARD (1901), who did not know this use of the word vulnerability, gave essentially the same warning as HORSFALL's committee [23].

In the last few decades botanical epidemiology has developed new views and accumulated a formidable amount of knowledge. Epidemiology has often been regarded as a 'research' activity, with relatively few possibilities for application. It is felt, however, that at present 'development' is making progress, which in the near future will lead to 'application' in practice, possibly within a framework currently indicated as 'plant disease management'. At the time of writing, 1975, the new trend in development and application belongs to the future, not to history.

## 2. HISTORICAL SURVEY OF BOTANICAL EPIDEMIOLOGY

### 2.1. HISTORY OF PLANT PATHOLOGY

The history of botanical epidemiology is largely the history of phytopathology, which has been well described. Among the papers covering periods of forty or more years are the following: AKAI, 1974; BERAN, 1951; BRAUN, 1965; ERIKSSON & HENNING, 1896; LARGE, 1950; MÄGDEFRAU, 1973; MAIER, 1959; OORT, 1968; ORLOB, 1971; QUANJER, 1949; RADEMACHER, 1967; REED, 1942; ROZENDAAL, 1969; SMITH, 1962; STEVENSON, 1959; WEHNELT, 1943; WESTERDIJK, 1941. WHETZEL's book (1918) merits special mention; he records trends and events up to 1918 but he does not, however, discuss epidemiology itself.

### 2.2. EARLY HISTORY (UP TO C. A.D. 1600)

Many epidemics are recorded in classical and medieval writings. Usually such disasters were attributed to divine wrath. More critical minds recognized the individuality – not to say personality – of epidemics. In medicine, an early leader was HIPPOCRATES (c. 460–380 B.C.). He distinguished sporadic and pandemic diseases, the latter being subdivided in endemic and epidemic diseases. Epidemic diseases occurred only in some years and then caused high morbidity or even mortality (OESTERLEN, 1873). The present use of the word pandemic in phytopathology is slightly different from this early use (GÄUMANN, 1946). In his first book 'On Epidemics', HIPPOCRATES' terse descriptions of some epidemics, such as mumps among young males in a gymnasium are impressive (JONES, 1972). HIPPOCRATES, often dealing with the disease now known as

- [24] 'More over, the position and character of the land make no small difference in this respect; for lands which are exposed to the wind and elevated are not liable to rust, or less so, while those that lie low and are not exposed to wind are more so.'

THEOPHRASTUS

IN: A. HORT, 1916

(Note by the authors: That cereal rusts develop faster or more in places sheltered from the wind, where dew periods are longer, can be seen up to this day.)

- [25] 'If we consider the contagions inductively, we shall see that the contagion of a putrefaction goes from one body to another whether adjacent or distant ... The seeds have the faculty of multiplying and propagating rapidly.'

FRACASTORO, 1546

IN: A. CASTIGLIONI, 1947

- [26] 'There are diseases of plants which do not contaminate animals, and vice versa animal diseases which do not attack plants; there are other diseases limited to man or to certain animals as cattle, horses and so on. Certain diseases have a special affinity for certain individuals or certain organs.'

FRACASTORO, 1546

IN: A. CASTIGLIONI, 1947

- [27] 'At Baiza in my own country, I have noticed cabbages attacked by syphilis. This disease is communicated to them by stagnant water in which the linen of syphilitic patients has been washed and which has been used afterward to water the plants. The swellings of these resemble the pustules of the disease to such a degree that the children cut them with shears and paste them on their faces to imitate the disease.'

RUIZ DIAZ DE ISLA

IN: M. WORONIN, 1934

- [28] '*Im 16. und 17. Jahrhundert blieb die Ursache der epidemischen Krankheiten noch ein grosser Mysterium. Selbst als die Vorstellung von den übernatürlichen Krankheitsursachen durch die natürlichen Ursachen ersetzt wurde, glaubte man noch an der göttlichen Ursprung der Krankheitserreger.*'

(In the 16th and 17th centuries, the origin of epidemic diseases still remained a great mystery. Even when the notion of the supernatural causes of disease was replaced by that of natural causes, people still believed in the divine origin of the pathogen.)

G. B. ORLOB, 1964a

- [29] '*... die unbekannte Ursache, welche das Alles bewirken sollte, nannte man epidemische Constitution, oft auch Genius epidemicus.*'

(... the unknown cause that would bring this all about was called epidemic constitution, often also *genius epidemicus*.)

F. OESTERLEN, 1873

malaria in its various forms, was well aware of environmental effects; as a medical practitioner he was an applied ecologist.

THEOPHRASTUS (372–287 B.C.) had accepted that environment determines or at least influences the incidence of plant diseases [24] (HORT, 1916), as did PLINY THE ELDER (A.D. 23–79). The latter mentioned soil and climate (temperature, precipitation, wind, etc.). The ancients were apparently aware of the phenomenon epidemic, but they had little more than an implicit idea about contagion.

The infectious character of some human diseases was well known in biblical times. In the later Middle Ages, sufferers from leprosy and plague were isolated in special wards. When a plague epidemic flared up in a town, well-to-do citizens fled to the country (GALE, 1959). It is said that the infectious nature of disease was first formally recognized during the Council of Trente (c. 1547), which, on the advice of GEROLAMO FRACASTORO, was adjourned and transferred to Bologna because of the plague (OESTERLEN, 1873). FRACASTORO, 'father of modern pathology' (CASTIGLIONI, 1947), had a remarkably clear perception of the existence of *seminaria prima*, seeds of contagion [25]. He also realized that diseases were host-specific [26]. The phenomenon of host-specificity had been overlooked by many ancient writers; WORONIN (1934) quotes the Spanish syphilographer RUIZ DIAZ DE ISLA, who claimed that cabbage plants suffer from syphilitic swellings [27], caused by *Plasmodiophora brassicae* according to WORONIN.

Until far into the 19th century epidemics on plants were a mystery [28] (ORLOB, 1964a). When God was no longer accepted as the source of all, good and evil, *miasmata* and other vague notions took his place (LARGE, 1950). Miasma (το μῶσμα) was the term used by HIPPOCRATES to indicate noxious emanations which he thought to be a cause of disease, a notion persisting until far into the 19th century. At times, criminal elements or social minorities were blamed (PARKIN, 1873; ORLOB, 1964a). In the words of OESTERLEN (1873), the unknown causes governed by the stars and present in the atmosphere or soil were indicated by the concept 'epidemic constitution' [29].

## 2.3. NEW HISTORY (C. 1600–C. 1850)

### 2.3.1. 17th Century

Empirical science came into being in the 17th century. The invention of the microscope was the source of a never-ending stream of biological research. In 1663 ANTONI VAN LEEUWENHOEK (1967) described micro-organisms isolated *i.a.* from his teeth. ROBERT HOOKE in 1665 published the first picture of a fungus, supposedly the teliospores of a *Phragmidium* (KEITT, 1959), but he did not recognize its nature or function (ORLOB, 1964a). In medical epidemiology, a first statistical approach was made by JOHN GRAUNT (1620–1674) and WILLIAM PETTY (1623–1687), who analysed the London Bills of Mortality (BAILEY,

1957; GALE, 1959). Of practical importance was the first plant protection legislation in Rouen (France), 1660, prescribing the eradication of barberry (*Berberis vulgaris*) bushes in view of their mysterious relation to wheat rust (*Puccinia graminis*) epidemics (LARGE, 1950). The chapter on the 17th century in the history of phytopathology has still to be written. Nothing can be said about epidemiology in that century, except that epidemics did occur (TOZZETTI, 1767). ANTONI VAN LEEUWENHOEK recorded a rust epidemic on pasture in September, 1648 [30] (VAN LEEUWENHOEK, 1967).

### 2.3.2. 18th Century

The history of phytopathology in the 18th century has not yet been adequately described. Many sources were quoted by TOZZETTI (1767), UNGER (1833), DE BARY (1853), and others, but undoubtedly other sources still await (re)discovery. Most sources are difficult of access. As a consequence, the following should be regarded as a first outline of 18th-century epidemiology.

In a masterly essay dated 1728, DUHAMEL DE MONCEAU discussed the epidemiology of a disease of the saffron crocus (*Crocus sativus*) called the Death, now known to be caused by *Rhizoctonia violacea*. He recognized epidemics on plants and compared them to those on animals, proved that the causal agent is

[30] 'Ik kan niet nalaten U.E. te zeggen, dat in de maand september van het jaar 1648 onze weiden als overstroomd waren door zeker roodachtig poeder, geheel gelijkende op de roest van het ijzer. En wanneer iemand door de gezegde velden wandelde, werd de genoemde stof, in onze ogen roestkleurig, waar de wandelaar tegen het gras stootte als poeder van het genoemde gras geschud. Dit veroorzaakte, dat men onder het volk algemeen zei, dat de lucht bovenmat vurig was; en des te meer omdat veel mensen door koorts werden aangestoken en daarom beelde het volk zich in, dat de rode poeder uit de lucht op het kruid of gras gevallen was.'

(I cannot omit to tell Your Honour that, in the month of September of the year 1648, our meadows were almost flooded by a certain reddish powder, entirely resembling the rust of iron. And when anyone walked through the said fields the substance mentioned, to our eyes the colour of rust, was shaken like a powder from the said grass wherever the walker hit the grass. For this reason it was a common saying that the air was excessively fiery; and the more so because many people were infected by fever, and therefore the common people believed that this red powder had fallen out of the air on to the herbs or grass.)

A. VAN LEEUWENHOEK, 1967

Note by the senior author: In the Netherlands, outbreaks of rusts (mainly *Puccinia coronata*) on pasture grasses (mainly *Lolium perenne* and *Holcus lanatus*) are not infrequent in late summer (late August, early September). Apparently, the epidemic mentioned by Van Leeuwenhoek was so severe, that the spores drifting in the air gave it a reddish hue, a phenomenon also known from severe wheat rust epidemics (but not in the Netherlands).

a biological entity *per se*, a parasite, and provided control techniques. DUHAMEL's paper is the first epidemiological paper known to the authors, and remarkably enough it treats a soil-borne root-invading disease, whereas present day epidemiology is often associated with shoot-inhabiting fungi only. DUHAMEL's experimental evidence that the parasite multiplies at the expense of the host attracted little attention in the scientific world. Had his finding been accepted, a century-long dispute on the parasitic origin of plant diseases could have been avoided.

The rusts and smuts attracted much interest in the 18th and early 19th centuries as can be seen in DE BARY's summary published in 1853. He did not, however, quote all authors, and notably not two Italian scientists living in Florence. Both were prompted to write on wheat rusts by the severe epidemic of 1766, which ravaged Italy, and the district of Tuscany in particular. FONTANA (1767) and TOZZETTI (1767) were both convinced of the parasitic nature of the rust (evidently *Puccinia graminis* f.sp. *tritici*), but they did not mention DUHAMEL's paper. Both 'philosophers' believed that the rust was dispersed by the wind, and both scientists attached much value to dry fogs during cool nights followed by hot days with burning sunshine. These environmental conditions are mentioned as favourable to rust development throughout the 18th and 19th centuries, and – indeed – modern knowledge supports this view, at least partially. Dew is mentioned by TOZZETTI. More fundamental is TOZZETTI's observation that the crop was excessively late due to late autumn sowing and cold winter weather, whereas the rust appeared relatively early. TOZZETTI provided and used detailed weather records, beginning with a description of the summer preceding the epidemic. The word epidemic was not used by the Florentine scientists.

The word experiment was fashionable in 18th century literature. By experiment FONTANA (1767) meant the close examination of his object, sometimes after a special preparation, by means of a microscope. The first real phytopathological experiment known to the authors was described by DUHAMEL in 1728; he inoculated pathogen-free soil with sclerotia of *Rhizoctonia violacea*, planted various crops in the inoculated soil and found that some crops died; on these crops the parasite had multiplied. More 18th century experimentation is known, that by TILLET (1755) being exemplary, but this experimentation bears no specific reference to epidemiology.

A word has to be said on the motivation of 18th century scientists, inasmuch as this is possible. In the 18th century, a sincere interest was taken in agriculture. Many experiments were done, and a great number of publications appeared on general agriculture. Some were written in answer to public prize contests, like that by TILLET (1755), the problems being dictated apparently by current agricultural problems. Authors motivated the interest in their subject as it 'merits the attention of one who is interested in the welfare of society' (FONTANA, 1767) or as a 'means of rendering less serious the dearth, proposed for the relief of the poor' (TOZZETTI, 1767). The interest of FABRICIUS THE DANE (1774), who was convinced of the contagiousness of plant diseases, though he supplied

[31] 'Knowledge of the diseases both of animals and plants forms an important part of our rural economy, but is still too much neglected ... With plants the condition is far worse; rural economy contains no complete description of their diseases.'

J. C. FABRICIUS, 1774

[32] '... a vast and difficult study, worthy of occupying the mind of any philosopher, both for the great value that it can bring to society and for the inward pleasure, little understood by the multitude, that is gained when one penetrates into the hidden secrets ...'

F. FONTANA, 1767

[33] '*Die Epoche der deutschen Pflanzenpathologie von 1800-1850 wurde deshalb als die romantische bezeichnet. Diese romantische Pflanzenpathologie war ganz im Sinne ihrer Zeit wesentlich auf Anschauung, gedankliche Erkenntnis, auf spekulative Deutung kranken Lebens eingestellt. Die Kunst des Experimentes war, bei gleichzeitiger Neigung und Fähigkeit zu genauer Beobachtung nur unvollkommen entwickelt.*'

(The era of German plant pathology from 1800 to 1850 was therefore described as the romantic. This romantic plant pathology was, entirely in accordance with the spirit of its time, essentially geared to contemplation, abstract knowledge, and speculative explanation of diseased life. The art of the experiment was only poorly developed alongside with preference and ability for accurate observation.)

B. WEHNELT, 1943

[34] '*Die Schwerpunkt der Fragestellungen lag nicht bei einem krankheitserregenden Lebewesen, sondern bei der kranken Pflanze selbst, ihrem krankhaften Leben und Bilden.*'

(The centre of gravity of the problems posed was not at the pathogenic living being, but at the diseased plant itself, its morbid life and development.)

B. WEHNELT, 1943

[35] '*Innerhalb des lebendigen Gefüges romantischer Universitas sind die Bindungen zwischen Pflanzenpathologie und romantischer Medizin, Naturphilosophie und Biologie nachweislich besonders eng und fruchtbar gewesen.*'

(Within the lively structure of the romantic *universitas*, the links between plant pathology and romantic medicine, natural philosophy, and biology were very close and fruitful as can be proved.)

B. WEHNELT, 1943

[36] '*Erst in neuester Zeit nämlich fängt man an, den Krankheiten unserer Nutzpflanzen grössere Aufmerksamkeit zu schenken, so dass man den Maassstab einer geläuterten Pflanzen-Anatomie und Physiologie anlegt, und die Krankheits-Erscheinungen in ähnlicher Weise zusammenfasst und in ihrem Zusammenhange darstellt, wie es die Pathologie bei Krankheiten der Hausthiere und Menschen vorschreibt.*'

(Only recently have people begun to pay closer attention to the diseases of our cultivated plants in order to apply the yardstick of pure plant anatomy and physiology, and to summarize the disease phenomena in a similar way and to depict them in their mutual relationship, as is required in the pathology of diseases in domestic animals and man.)

C. F. P. VON MARTIUS, 1842

[37] '*Auch der (Human-)Patholog gewinnt durch die Kenntnis der botanischen Vorgänge die wertvollsten Anknüpfungspunkte für das Verständnis der Krankheiten.*'

(From knowledge of botanical processes, the (human) pathologist too gains invaluable points of reference for the understanding of diseases.)

R. VIRCHOW, 1858



no proof, was plainly economical [31]. Besides the published motivation there must have been a more covert one, the satisfaction, the fun of entering a new world of discovery, as confessed by FONTANA [32].

### 2.3.3. 19th Century, first half

Soon after Europe had recovered from the Napoleonic wars, the romantic era set in. Romanticism also coloured medicine (CASTIGLIONI, 1947) and the natural sciences (MÄGDEFRAU, 1973), where keen observation without the opportunity for experimentation led to speculative thinking [33] (WEHNELT, 1943). The emphasis of 'romantic phytopathology' was on the diseased plant [34] and its symptomatology. The pathogen, if recognized, was often regarded as the effect rather than the cause of the disease. Typically, the word exanthema (an eruption or rash of the skin) was used (UNGER, 1833). WHETZEL (1918) called this period, roughly the first half of the century, the 'physiological' or 'autogenetic' period; WEHNELT (1943) labelled it the 'romantic' period.

Phytopathology, not yet a discipline in its own right, was often undertaken by doctors of medicine. UNGER (1833), being a medic, was certainly influenced by the humoral pathology of his time. Only few people, many of whom had a medical training, were engaged in the natural sciences, which were not yet very diversified. There was a kind of unity of sciences, here to be indicated by the word 'holism', a unity quite favourable to new developments [35] (WEHNELT, 1943). It is worth noticing that mycologists, though participating in the unity of sciences, were rarely involved in phytopathology (ORLOB, 1964a). Those interested were usually botanists, who followed the example set by the medical fraternity [36] (VON MARTIUS, 1842). Phytopathology also affected human medicine [37] (VIRCHOW, 1858), but in medicine the final proof of the existence of independent pathogens by ROBERT KOCH in 1876 came later than in phytopathology (MÄGDEFRAU, 1973). 'Relevance' as an argument for studying plant diseases seems to be rare in the first half of the 19th century. General interest in agriculture continued after the 18th century, but why medical doctors became plant pathologists is not clear. The work of PRÉVOST (1807) on *Tilletia tritici* was an answer to a public prize contest, in the 18th-century tradition. There was a growing awareness that epidemics on crops must be caused by infectious agents, and were favoured by specific conditions, but contemporary experimental evidence is almost non-existent [38, 39].

## 2.4. BIRTH OF PHYTOPATHOLOGY

### 2.4.1. 19th Century, second half

The great epidemic of potato late blight (*Phytophthora infestans*), which unexpectedly struck north west Europe, changed the relative euphoria of the epoch. The tremendous economic and social impact of the 'blight' gave phytopathology the relevance it needed to become a discipline in its own right.

[38] *'Die Ansicht vom Wesen der Entartung und deren Fortpflanzung vom Kartoffel-Epidemie bleibt allen jenen Zweifeln unterworfen, die man rücksichtlich der Natur der Epidemien und Contagien überhaupt noch hegen muss ...'*

(The conception of the nature of the degeneration and of the transmission in the potato epidemic remains subject to all possible doubts that one still must entertain with respect to the nature of epidemics and contagia.)

C. F. P. VON MARTIUS, 1842

[39] *'Wie unter der Aerzten, herrschen auch unter den Botanikern verschiedene Meinungen über die Natur der Pflanzen-Epidemien, sofern diese von einem eigentümlichen Contagium getragen werden oder nicht. Meine Erfahrungen leiten mich mehr und mehr zu der Annahme, dass den epidemischen Krankheiten im Gewächsreiche irgend ein concretes Substrat unterliege, welches unter gewissen, begünstigenden Umständen Krankheit hervorzurufen vermöge.'*

(As among medical practitioners, several opinions exist among botanists about the nature of plant epidemics, in that they are carried by a characteristic *contagium* or not. My experience has drawn me more and more to the conclusion that somehow there is some concrete principle underlying epidemic diseases in the vegetable kingdom which may call forth disease under certain favourable conditions.)

C. F. P. VON MARTIUS, 1842

[40] Cryptogamous origin of malarious and epidemic fevers.

J. K. MITCHELL (book title), 1849

In: A. CASTIGLIONI, 1947

[41] *'Aber nicht Worte und Phrasen sind es, die uns dazu führen – Resultate, praktisch bedeutsame Resultate müssen wir Aufzeigen können, und um dies zu vermögen, müssen wir einsehen lernen, dass methodisch untersuchen, klar sehen, scharf beobachten und den naturgesetzlichen Zusammenhang der Erscheinungen richtig auffassen lernen, die wahre Frucht naturwissenschaftlicher Studien ist: ...'*

(But it is not words nor phrases that will lead us to this – it is results, practical meaningful results that we must bring forward. And to do so, we must learn to investigate methodically, to discern, to see clearly, to observe closely, and to understand rightly the regular interrelationship of phenomena, that is the true fruit of natural science.)

J. G. KÜHN, 1858

[42] *'Wie die Epidemien unter Menschen und Thieren plötzlich und unerwartet auftreten, eine Zeit lang über ganze Länderstrecken Verderben verbreiten und sich dann allmählig verlieren, so auch die Pflanzenepidemien.'*

(Epidemics among man and animals appear suddenly and unexpectedly, spread destruction over whole regions for a while and then slowly disappear and so do plant epidemics.)

J. G. KÜHN, 1858

[43] *'Im Jahre 1916 sollte es leider anders kommen. Diese Jahr brachte uns die kleinste Kartoffelernte seit vielen Jahren, dadurch wurde unsere wirtschaftliche Durchhaltungsfähigkeit wirklich ernstlich bedroht, zumal nicht nur jede Einfuhr fast ganz ausblieb, von der wir sonst in Friedensjahren erheblichen Gebrauch gemacht hätten, sondern sogar noch verbündete und neutrale Länder mit Kartoffelmengen, allerdings wohl nicht sehr beträchtlichen, versorgt werden mussten.'*

(Unfortunately, the year 1916 proved different. That year brought us the smallest potato harvest for many years, seriously threatening our economic resilience since not only there was practically no importation of which we otherwise made considerable usage in peace time, but also since allied and neutral countries had to be supplied with potatoes, although not in large amounts.)

STÖRMER, 1918

The discipline was born (TEN HOUTEN, 1959; OORT, 1949) in 1858 when the first comprehensive textbook was published by KÜHN, widely acknowledged as the Father of Modern Plant Pathology (WHETZEL, 1918).

The discussion, that had been going on for several decades, between the 'autogenitists' and the 'pathogenitists' was soon decided in favour of the pathogenitists (WHETZEL, 1918), as in medicine [40]. Convincing evidence, descriptive but not yet experimental, for the independent existence of pathogens was put forward by DE BARY in 1853. Mycology flourished and was also applied to diseased plants. But the fundamental change was the introduction of the experiment to demonstrate that fungi could be causal agents of plant diseases, an advance which made it possible to unravel the etiology of many diseases [41]. Among the famous mycologists of the period were BERKELEY in the United Kingdom, the brothers TULASNE in France, and DE BARY in Germany. The experimental evidence provided by SPEERSCHNEIDER (1857) and DE BARY (1861) with *Phytophthora infestans* on potatoes and other comparable experiments elucidated (parts of) the life cycles of these fungi. These results shifted the general interest towards the pathogen as an individual worthy of detailed observation, description, and classification (ORLOB, 1964a). In 1865, DE BARY described the mysterious alternation of generations and hosts, a finding of great epidemiological importance, which justified the legislature of Rouen after two centuries.

Though there was no lack of speculation about the causes leading to epidemics, epidemiology as it is understood now was hardly studied. HLUBEK's proposal in 1847 to start regular meteorological observations, because they might help to solve the riddle of the origin of diseases – in addition to effects of soil, manure, and planting data – was not effectuated (MAYER, 1952; WEHNELT, 1943). In his 1858 textbook, KÜHN recognized the importance of epidemics on crop plants, and compared them to epidemics affecting men or animals [42].

The period between the potato murrain of the 1840s and that in Germany during World War I, another epidemic with political implications as it contributed to the outcome of a war [43, 44] (STÖRMER, 1918; LÖHR, 1954), was used to organize and develop phytopathology. The organization was built up on national and international lines, with private and governmental initiatives. Governments started to accept plant protection as a public task. National institutions were set up (Table 1), phytopathological societies and journals were initiated (Tables 2, 3), and teaching began (Table 4). Two personalities of international standing played a key-role in the structuring of plant protection including phytopathology and epidemiology: SORAUER and ERIKSSON. In view of many of his publications, the latter can certainly be regarded as an epidemiologist. In the United Kingdom, H. MARSHALL WARD took an epidemiological point of view. He began his career by studying an epidemic of coffee rust (*Hemileia vastatrix*) in Ceylon. His textbook 'Disease in Plants' (1901) shows a typical ecological approach in chapters on 'spreading of disease and epidemics' and 'the factors of an epidemic' [45].

[44] *'Diese Hungersnot, hervorgerufen durch die Kartoffelpest, hat die Widerstandskraft des Deutschen Volkes gebrochen. Der Soldat wusste seine Angehörigen daheim dem quälenden Hunger preisgegeben. Dies lähmte seinen Kampfwillen. Es hat ja alles doch keinen Sinn, sagte sich der Mann an der Front.'*

(This famine, caused by the potato blight, has broken the resistance of the German people. The soldier knew that his relatives at home were tormented by hunger. This paralysed his will to fight. All this has no meaning, said the man at the front.)

F. LÖHR VON WACHENDORF, 1954

[45] 'When we come to enquire into what circumstances bring about those severe and apparently sudden attacks on our crops, orchards, gardens and forests by hosts of some particular parasite, bringing about all the dreaded features of an epidemic disease, we soon discover the existence of a series of complex problems of intertwined relationships between one organism and another, and between both and the non-living environment which fully justify the caution already given against concluding that any cause of disease can be a single agent working alone.'

H. MARSHALL WARD, 1901

[46] *'Die Erkenntnis, dass die Zeitschrift für Pflanzenkrankheiten ein notwendiger Hebel für den Ackerbau geworden ist, der gerade jetzt wesentlich an der Steigerung der sinkenden Bodenrente durch Erhaltung der Ernten mitwirken kann, hat die Aufmerksamkeit und das Wohlwollen der Behörden auf sie hingelenkt und ihr die öffentliche Empfehlung seitens des kgl. preuss. landwirtsch. Ministeriums und des k.u.k. österr. Ackerbau-Ministeriums eingetragen.'*

(The realization, that the *Zeitschrift für Pflanzenkrankheiten* has become a necessary husbandry, which especially at this moment can help essentially to improve decreasing land rents by the preservation of crops, has attracted the attention and the benevolence of the authorities. The Royal Prussian Ministry of Agriculture and the Imperial and Royal Austrian Ministry of Agriculture have both publicly recommended the journal.)

P. SORAUER, 1894c

[47] Question 95. *'Quelles sont les mesures introduites jusqu'à présent par les divers Etats d'Europe, notamment au point de vue de l'organisation, pour favoriser l'étude des maladies des plantes agricoles et pour en diminuer les mauvais effets? Que peut-on et que doit-on faire encore dans ce sens?'*

*'Résolutions: 1°. Considérant que les maladies des plantes, très importantes au point de vue agricole, causent aux particuliers et par suite à l'Etat des pertes souvent fort considérables et que les moyens curatifs et prophylactiques dont on dispose pour en diminuer les ravages ne sont que d'une très faible efficacité, il serait bon d'établir des stations d'essais phytopathologiques.'*

*'Résolutions: 5°. Pour poursuivre la question dans la direction donnée, le Congrès élit une commission internationale, ayant droit de cooptation qui aura à se mettre en rapport avec la Société I.R. d'Agriculture de Vienne et différentes Sociétés semblables, qui ont leur siège dans l'autres Etats européens pour s'entendre avec elles sur les démarches à faire dans le but de créer les stations.'*

(Question 95. What measures have so far been introduced by the various countries of Europe especially with respect to organization, in encouraging the study of diseases of agricultural plants and in reducing bad effects? What can one do and what must one do yet on this matter?)

The second half of the 19th century has been called the *naturwissenschaftliche Periode* (WEHNELT, 1943), as the causes of plant diseases were studied by experimental methods. Towards the end of the century these included the etiological tests according to the postulates of KOCH (1890), another beneficial effect of medicine on plant pathology. In WHETZEL's (1918) terminology, the period was composed of the 'Kühnian' period, during which fungi were identified as possible causes of diseases and epidemics, and the 'Millardetian' or 'economic' period, in which chemical control was shown to be economically feasible. WHETZEL's near-contemporaneous viewpoint is too restricted; bacteria and viruses were recognized as possible causes of disease, and KÜHN had founded plant nematology. HUGO DE VRIES (1896), Dutch botanist, one of the re-discoverers of MENDEL's rules of inheritance, stimulator of plant pathology in the Netherlands, described an epidemic of virescence, now known to be caused by a mycoplasma, on plants in a botanical garden.

Plant quarantine regulations were set up in most developed countries to get a grip on the importation of undesired plant pest and disease organisms. 'Relevance' took the form of economic necessity. The opening up of the American prairies was a major cause of a deep depression in European agriculture in the 1890s [46] (VON PROSKOWETZ, 1890; SORAUER, 1894c), which led governmental authorities to promote agricultural research including plant protection.

#### 2.4.2. *Internationalism in plant protection*

Pests and diseases do not stop at national borders, but some can be halted by interception. Besides adequate knowledge, the technique needs public support and a minimum of public organization. Towards the end of the 19th century, the time was ripe. The San José Scale (*Quadrastpidiotus perniciosus*) was the great menace, and entomologists led the way to counter-measures.

In 1890, the International Congress of Agriculture and Forestry took place in Vienna. On the proposal of J. ERIKSSON from Sweden and P. SORAUER from Germany an International Phytopathological Committee was charged with the task of stimulating the initiation and co-ordination of phytopathological research stations [47] (VON PROSKOWETZ, 1890). The congressional resolutions

Resolutions: 1°. Since plant diseases, very important for agriculture, cause often very considerable losses to private industry and consequently to the state and since the available means of cure and prevention to reduce damages are so inefficacious, it would be good to establish plant pathology research stations.

Resolutions: 5°. To pursue this matter in the direction indicated, the Congress elects an international commission with the right of cooptation which will report along with the *Société I.R. d'Agriculture de Vienne* and various similar societies with their seat in other European countries to come to agreement with them about steps needed in creating such stations.)

M. VON PROSKOWETZ, 1890

were quite effective, see Table 1. The cooperation of the Committee with the *Zeitschrift für Pflanzenkrankheiten* to select the best results of *aller Kulturvölker der Erde* for publication lasted from 1891–1899 (SORAUER, 1891c; 1894c). In a series of international agricultural congresses the importance of phytopathological organizations and international collaboration has been emphasized [48] (SORAUER, 1891b; ERIKSSON, 1915; SORAUER, 1905a). The International Agricultural Congress in Rome (1903) initiated an International Phytopathological Committee with P. SORAUER as its chairman, and Berlin as its seat. This was a committee of scientists without governmental support (ROGERS, 1914). The International Agricultural Institute, founded in Rome,

[48] *'Le Congrès est d'avis qu'il y a lieu de reconnaître que le secours le plus puissant que la science pourra prêter à la culture générale des plantes dans un temps rapproché doit consister dans l'organisation d'observations systématiques des maladies, épidémies, ou des ennemis des plantes, pour étudier les moyens de les combattre et que pour atteindre ce but il est nécessaire qu'un personnel scientifique ainsi que des praticiens de tous les pays se vouent à ces observations d'une manière méthodique et en se prêtant une assistance mutuelle.'*

(The Congress thinks it right to acknowledge that the most powerful contribution science could make in the near future to general crop husbandry is the organizing of systematic observations on diseases, pests, and enemies of plants, to study means of combating them, and that to achieve this objective, scientific personnel and practitioners of all countries devote themselves to these observations in a methodical way, offering one another mutual assistance.)

P. SORAUER, 1891b

[49] *'Let us not be among the last of the groups of scientists who shall accept the great responsibility and improve the wonderful opportunity now offered for world service in advancing science and promoting the brotherhood of mankind.'*

C. L. SHEAR, 1919

[50] *'The relation of environment to the pre-disposition of the host, as well as to the virulence of the parasite cannot be over-emphasized.'*

L. R. JONES, 1913

[51] *'There are three phases in the history of plant pathology: First, the period of De Bary in which the fungus held first place; second, the period in which the host received most attention; and finally, the present period in which disease is considered as an interaction of both under the conditioning influence of the environment. The leader in this is Jones.'*

E. J. BUTLER, 1926

In: G. W. KEITT & F. V. RAND, 1946

1905, organized an International Phytopathological Conference at Rome in 1914, where scientists from thirty countries were present. The technical proposals all involved epidemiology, without using the word: Seed Certification Schemes, Import Restrictions, and Statistical Surveys (national and international) (ERIKSSON, 1913; ORTON, 1914). The proposals for international cooperation could not materialize as World War I broke out (ERIKSSON, 1915; ROGERS, 1914).

During World War I the U.S.A. took over the lead in plant pathology from Europe (ERIKSSON, 1915; SHEAR, 1913). After the war, internationalism flowered [49] (SHEAR, 1919), and wilted, although in 1924 the words 'an international journal' were added to the title of the national U.S. journal 'Phytopathology', a symbolic deed (ANONYMOUS, 1911). The European editor up to World War II was H. M. QUANJER, Wageningen, the Netherlands (MACCALLAN, 1959). Formal international developments had to wait until after World War II, but at the national level the objectives were realized in most developed countries, thus also providing basic information for epidemiology.

#### 2.4.3. *Holistic tendencies, the 'second wave'*

Around 1910, when the movement for international phytopathology gained impetus, holistic tendencies reappeared. It was clearly stated that phytopathological problems were world-embracing problems [15] (ORTON, 1914; see also 2.4.2.). The relation between outbreaks of disease, weather, and climate was again emphasized. The word ecology appears in publications on botanical epidemiology. The influence of environment on predisposition of the host and virulence of the parasite is emphasized once more [50] (COLHOUN, 1964). One could say that the 'predispositionists' headed by SORAUER are the successors of the autogenitists of the 19th century (WHETZEL, 1918).

Holistic tendencies became apparent in statements that placed plant pathology in a wider context. The title of the inaugural lecture given by RITZEMA BOS (1895b), when he accepted the chair of phytopathology at Amsterdam University, 29 November 1895, dealt with the contribution of phytopathology to the biological sciences. ORTON (1914) wrote a paper with a set of clear objectives on the biological basis of international phytopathology [15]. There seems to be a growing relation between plant and animal pathology as expressed by a common terminology (HARDING, 1912). One reason for the holistic tendencies might be found in the educational background of the leaders in the field, who had medical, botanical, or zoological training. In Germany and the Netherlands, phytopathology included the zoological aspects (RITZEMA BOS was a zoologist), in contrast to France, the United Kingdom, and the U.S.A. (MORSTATT, 1921, 1929; ORLOB, 1964b; RADEMACHER, 1966).

E. J. BUTLER recognized three phases in the history of plant pathology from 1850 to 1925 [51] (KEITT & RAND, 1946), with emphasis on the fungus, the host, and the interaction with the environment, respectively. Another view of the three phases was given by MORSTATT, 1921, who distinguished the phases of the study of the causal organism, the control of the causal organism, and the

hygienic-therapeutic approach; epidemiology is mentioned as a distinct subject [52]. It is possible that the holistic tendencies of the period were in part a reaction to the relative ineffectiveness of applied phytopathology, but that has been stated nowhere. These tendencies have been of great heuristic value, as they opened up new and fertile fields of research.

[52] *'Hierbei trat eine ganze Anzahl anderer Gesichtspunkte und Richtungen hinzu. Von diesen gehören zu einer Epidemiologie die Fragen des Einflusses der Witterung und anderer Faktoren der Umgebung, wie z.B. des Bodens, der Wanderung und Verschleppung von Krankheitserregern und ihrer Überträger; die Fragen der Anfälligkeit und Widerstandsfähigkeit der Sorten, woraus auf praktischem Gebiete die Immunitätszüchtung hervorging; der Virulenz der Erreger; ferner die sgn. biologische Bekämpfung, u.s.w.'*

(A whole range of other viewpoints and orientations here come to light. To epidemiology belong questions on the influence of the weather and other environmental factors, such as the soil, migration and transportation of pathogens and their vectors; the questions on susceptibility and resistance of varieties, from which ensues in the practical field the breeding for resistance; on virulence of the pathogen; further on the so-called biological control; etc.)

H. MORSTATT, 1921

[53] *'Von den verschiedensten Seiten ist in den letzten Jahren mit steigendem Nachdruck auf die epidemiologischen Lücken im Wissensbereich des Pflanzenschutzes hingewiesen und insbesondere ein Ausbau unserer Kenntnisse über das Ausbrechen, die Art des Verlaufs und das Wiederverklingen der Seuchenbedingenden Faktoren gefordert worden.'*

(During recent years, people from the most diverse backgrounds have pointed more and more emphatically to the epidemiological gaps in the science of plant protection. In particular more facts must be obtained on the outbreak, course and decline of disease-causing factors.)

H. BLUNCK, 1929

[54] *'Auf allen Gebieten, auf denen es möglich ist, soll Deutschland in vier Jahren unabhängig vom Auslande sein. Dieser Plan verlangt von allen Wirtschaftskreisen, auch von der Landwirtschaft, höchste Anstrengung. Er gibt neuen Auftrieb der vom Reichsbauernführer im Jahre 1934 verkündeten "Erzeugungsschlacht" und dem im Herbst 1936 erklärten "Kampf dem Verderb" ... Der Führer verlangt die Durchführung des Vierjahresplanes; dann müssen aber auch die Mittel dafür zur Verfügung gestellt werden. ...'*

(In four years time, Germany must be independent of foreign countries in all areas possible. This plan requires tremendous efforts from all sectors of the economy, including agriculture. It gives a new impulse to the 'production battle' proclaimed in 1934 and the 'war against destruction' proclaimed in autumn 1936 by the State Farmers' Führer... The Führer demands implementation of the four-year plan but to do this, people must be provided with the means. ...)

E. RIEHM, 1937



## 2.5. THE PERIOD BETWEEN WORLD WARS I AND II

During World War I, phytopathologists shifted their attention to more 'relevant' research, research in the field, to safeguard and increase food production (HORSFALL, 1969b). The peak was reached shortly after World War I, but later on the interest of researchers was spread more evenly over various approaches within their discipline. There is little doubt that epidemiological studies ranked high among the 'relevant' research [53] (BLUNCK, 1929; BREMER, 1926; MORSTATT, 1921). This is, however, difficult to demonstrate because then plant pathology was not compartmentalized as it is now (1975), and, accordingly, many publications covered several aspects of a problem, including the epidemiological aspect (MAAN & ZADOKS, in press).

Three major features became apparent in the period between the World Wars. 1: Resistance breeding came into being and changed epidemiological patterns all over the world. 2: Disease forecasting services, useful because chemical disease control became possible, were developed on the basis of more or less detailed epidemiological information (MORSTATT, 1929). 3: Physiological (and primitive biochemical) research methods were also applied in phytopathology and brought chemotherapy within reach. Generally speaking, the period between the two World Wars engendered the now classical phytopathological methods intended to find the cause of a problem met with in practical agri-, horti- or silviculture by means of laboratory methods (KERLING, 1966).

In 1934 Germany initiated a four-year crash program to become self-supporting in agriculture, including the intensification of crop protection research; a prelude to World War II [54] (RIEHM, 1937).

## 2.6. THE PERIOD AFTER WORLD WAR II

### 2.6.1. *Holistic tendencies, the 'third wave'*

In World War II the 'relevant' field-oriented research was stepped up again, as during World War I. The American Phytopathological Society set up a War Emergency Committee in 1942 [16] (WAR EMERGENCY COMMITTEE, 1942); a better organized, nation-wide plant disease survey service was advocated. Publication of field-oriented research reached a peak shortly after the war, when results had piled up and scientists shook off wartime stress and settled down to write (HORSFALL, 1969b; MAAN & ZADOKS, in press).

After World War II, the swing of the pendulum went towards basic science; in phytopathology this meant towards physiological and biochemical approaches. Most of the money and practically all the bright young students were engaged in the biochemical sector, thus leading to an outbreak of new knowledge, and finally to a stream of useful systemic biocides (ZADOKS, 1974a). The change to fundamental and applied biochemical research was strongest in the U.S.A. In the U.K. and in the Netherlands, epidemiological research

continued quietly. In Germany, heavily damaged by the war, agriculture in general and phytopathology in particular had low priority in post-war reconstruction; epidemiological research was taken up again around 1960. In France, a few researchers were engaged in typical epidemiological studies. Their publications can be found in various national journals on phytopathology and related subjects.

In the sixties, when ecology became fashionable, the holistic (KRANZ, 1974b) approach had a new upsurge. A number of factors contributed to this renaissance, among which a few can be pinpointed here. Environmental protection and the fight against pollution attracted a great number of students who wanted to do something for mankind, something 'relevant', whatever that may be. In part, this was a reaction to the fundamentalism of basic science. The International Biological Program, sponsored by UNESCO and financed by individual governments, mobilized a great number of biologists and other scientists, and led to many new and internationally accepted techniques (see a.o. I.B.P. Handbooks). In medicine and related sciences renewed interest in the effects of weather and climate led, in 1956, to the founding of the International Society of Biometeorology (see 2.6.2). Last but not least, universities produced increasing numbers of young scientists with a far greater variety of interests, motivations, outlooks on life, and objectives than ever before.

In addition to these general trends, a few specific developments can be mentioned. GREGORY's book 'The Microbiology of the Atmosphere' (1961) is a birth-certificate of aerobiology, a branch of biology born long before it was certified; it had a great impact on epidemiology. Mathematics were introduced in botanical epidemiology by VAN DER PLANK in his brilliant book on epidemics and control (1963), later followed by systems analysis (WAGGONER, 1968; ZADOKS, 1971; KRANZ, 1974a). The mutual effects of plant breeding and epidemiology were recognized (see 3.7.). The economic and social point of view of plant diseases, and of epidemics especially, were called to the attention of governments and scientists by FAO in the FAO Symposium on Crop Losses (FAO, 1967). The International Society of Plant Pathology has invested a Commission on Crop Losses in 1973.

[55] 'Biometeorology comprises the study of the direct and indirect interrelations between the geophysical and geochemical environment of the atmosphere and living organisms, plants, animals and man.'

S. W. TROMP, 1963

### 2.6.2. *International organization*

After World War II, several developments took place more or less independently. National plant protection services got together in regional organizations, for the co-ordination of quarantine problems, import and export regulations, and action in specific problems. In Europe, they started with an acute problem, the Colorado beetle (*Leptinotarsa decemlineata*), which led to the establishment of an International Colorado Beetle Control Committee in 1946 (WILKINS, 1964). This Committee was succeeded in 1950 by the European Plant Protection Organization, later European and Mediterranean Plant Protection Organization. Initiated to deal with entomological problems, the organization also had to take action in phytopathological problems. Epidemiology was not an objective of the organization, but at times it became a means towards an end. In the medical world, biometeorology came into being [55] (TROMP, 1963). Thanks to the infatigable S. W. TROMP, an International Society of Biometeorology was founded in 1956. Botanical aspects were covered by the Main Group 'Phytological biometeorology', with a Section 'Pathological phyto-biometeorology' (TROMP, 1963). Contacts with the U.S. Committee on Epidemiology and Meteorology of the American Phytopathological Society (A.P.S., 1964) led to the organization of a NATO Advanced Institute on the epidemiology of plant diseases as a part of the Third International Congress of Biometeorology in Pau, France, 1963. This strictly invitational meeting, NATO Advanced Study Institute 'Epidemiology of fungal pathogens', organized by R. D. SCHEIN and J. M. HIRST, later assisted by A. J. P. OORT and J. C. ZADOKS, where some forty participants from fourteen countries met, triggered off a new development (HIRST, 1964). Botanical epidemiology became internationally accepted and started to attract renewed interest among students and teachers. In 1971, a second NATO Advanced Study Institute 'Epidemiology of Plant Diseases' was organized by ZADOKS, SCHEIN, and HIRST, assisted by H. D. FRINKING, in Wageningen, the Netherlands. Some 74 participants from 24 countries and 5 continents participated in this invitational meeting; exhaustive discussions took place but no proceedings were issued (BUTT, 1972; ZADOKS, 1972).

At international congresses on botany and agriculture, phytopathology has always been a topic. Although a first International Phytopathological Congress had been held in Wageningen, the Netherlands, in 1923 (SCHROEVERS, 1923), plant pathology acquired its own series of international congresses only late after World War II. The First International Congress of Plant Pathology was held in 1968, in London. There was a section Epidemiology, organized by J. M. HIRST, with 6 sessions, including one on epidemiology in the tropics. This line of development was continued at the Second International Congress of Plant Pathology, Minneapolis, 1973, where a committee chaired by R. A. SCHMIDT organized 10 sessions and a demonstration. One session dealt with Epidemiology Teaching (see 4) and one with Comparative Epidemiology, in which comparisons were made between root and foliar diseases, and between diseases caused by fungi and viruses. The virologists had their own session on epidemiology.

### 3. BOTANICAL EPIDEMIOLOGY AND COLLATERAL ACTIVITIES

#### 3.1. GENERAL REMARKS

Botanical epidemiology as a research topic is so narrowly defined that it would be difficult to attach any other label to it. As a professional activity, however, botanical epidemiology is always intertwined with other topics, e.g.

[56] *'Der Deutsche Landwirtschaft beschliesst bei der Reichsregierung in Anregung zu bringen, dass durch ein Zentralorgan alle Beobachtungen über Erscheinung, Verbreitung und Bekämpfung der von Tieren, Pilzen oder anderen Ursachen herbeigeführten Beschädigungen unserer landwirtschaftlichen Kulturpflanzen gesammelt und eine systematische Zusammenstellung und Bearbeitung solcher Beobachtungen alljährlich der Öffentlichkeit übergehen werde.'* ... *'Dieser Beschluss scheint keine praktischen Erfolge erzielt zu haben ...'*

(German agriculture resolves to request the Government that a central body collect all observations on appearance, distribution, and control of damages to our agricultural crops caused by animals, fungi or other causes, and that the body systematically compile and process such observations for annual publication. ... It seems that this resolution has had no practical consequences ...)

P. SORAUER, 1892

[57] *'Der Pflanzenschutz muss eine eigene Disziplin der Wissenschaft bilden.'* ... *'Nicht nur das Vorkommen der Krankheiten soll registriert werden, sondern auch der Intensität der Verbreitung in einzelnen Herden soll durch Feststellung der begleitenden Nebenumstände allmählig klar gelegt werden, welche Witterungs-, Boden- oder Bewirtschaftungsverhältnisse die Intensität der Ausbreitung bedingen. Auf diese Weise gelangen wir zur Erforschung der Ursachen, welche Endemien und Epidemien bedingen. Nach dieser Erkenntnis wird man vielfach vorbeugend einzugreifen lernen, und es wird dann eine Pflanzenhygiene geschaffen werden. Das ist das Ziel der Statistik.'*

(Plant protection must build a scientific discipline of its own. ... Not only the incidence of diseases must be recorded, but also the intensity of occurrence in particular centres must be gradually established, by determining the associated secondary factors as determined by weather, soil, or crop husbandry. In this way, we can investigate the causes of endemics and epidemics. With this knowledge, we will often be able to take preventive action, and a discipline of plant hygiene will be created. This is the purpose of statistics.)

P. SORAUER, 1905b

[58] *'How can we expect practical men to be properly impressed with the importance of our work and to vote large sums of money for its support when in place of facts we have only vague guesses to give them and we do not take the trouble to make careful estimates.'*

G. R. LYMAN, 1918

In: W. CLIVE JAMES, 1974

etiology, disease and loss assessment, phenology and meteorology, and chemical control. The borderlines of epidemiology have not yet been drawn sharply. For example, during the Second International Congress of Plant Pathology, Minneapolis, 1973, many participants with an interest in epidemiology had to choose between simultaneous sessions.

Disease assessment is near to becoming an objective in itself; at the same time, it is an indispensable instrument for epidemiologists. Loss assessment has certainly become an objective in its own right; however, it can also be regarded as the logical end-point of epidemiological studies. The latter is also true for disease and loss forecasting, to which purpose meteorology is a necessity. Mathematics of various kinds have been applied in epidemiology, and mathematical principles have become indispensable to epidemiological theory. It has been shown in recent years that resistance breeding has changed the behaviour of several diseases, and that epidemiological considerations can contribute to resistance breeding. General ecological principles pertain to epidemiology and, in a way, epidemiology can be regarded as the ecology of unbalanced systems.

This chapter serves to unravel some of the interrelations between various disciplines and specialisms, and to look for a few historical lines of thought.

### 3.2. DISEASE AND LOSS ASSESSMENT

Systematic disease and loss assessment over a long series of years and a large area provides epidemiologists with useful information, especially in conjunction with similar information on weather, varieties, and cultural practices. The concept of disease assessment was put forward in the second half of the 19th century; the concept of loss assessment as opposed to the authoritative opinion of the specialist (CREELMAN, 1968) is of recent origin.

On KORN's suggestion in 1880, the German government was approached to set up a central plant disease and pest registration [56]. As the government did not react, the German Agricultural Society itself began this work in 1890. The 1890 Vienna congress was explicit about what is now called disease assessment [48] (SORAUER, 1891b). In 1895, loss assessment had been started in Germany by the Preussische Landwirtschaftliche Ministerium (SORAUER, 1894a). In 1905, SORAUER clearly stated the objectives of these descriptive statistics, relating it to information on weather, soils, and agricultural practices (not cultivars!) [57]. During a couple of years around 1910, the International Institute of Agriculture, Rome, had a Bureau of Agricultural Intelligence and Plant Diseases, which issued statistical information. World-wide, national, and regional surveys were advocated, along the general lines followed in Germany and the United States (ORTON, 1914). In the U.S.A., a Plant Disease Survey was started in 1917, with a.o. the task of mapping epidemics [58] (LYMAN, 1918). The then recent chestnut blight epidemic (*Endothia parasitica*), originating in China but ravaging the American chestnut forests, was an eye-opener. In Germany, the necessity of quantitative observations was stressed

[59] (BREMER, 1926). The need to collect weather data was also underlined (BLUNCK, 1929). Many countries have followed the example set by Germany and the U.S.A., so that much information has been assembled, but the contribution to the advancement of science has been meagre.

A new trend was developed in the U.K. after World War II. W. C. MOORE, in his introduction to the new journal 'Plant Pathology', announced a.o. disease and weather surveys, and crop loss estimates (MOORE, 1952). British entomologists had led the way in pest assessment schemes [60] (STRICKLAND, 1953). At the suggestion of Lionel P. SMITH (Meteorological Office), the Harpenden Experimental Station of the Ministry of Agriculture organized a nation-wide network of field-plots for the study of potato late blight forecasting, complete with loss assessment (LARGE, 1953). One may say that a Harpenden school of disease and loss assessment developed, with A. H. STRICKLAND as the entomologist (STRICKLAND, 1953), E. C. LARGE and Miss F. JOAN MOORE as the mycologists; their work had great impact on later events.

Although the U.K. developed the most advanced system of loss assessment, disease assessment schemes were set up in many countries. In Germany, the schemes were a continuation of the traditional interest in phenology, the objective being to develop forecasting systems (MÜLLER, 1957; STOLZE, 1955; UHLIG, 1954). In recent years, with the endorsement of F.A.O. and I.S.P.P. disease and loss assessment has become quite sophisticated (CLIVE JAMES, 1974; CHIARAPPA, 1971).

[59] *'In allen übrigen Fällen aber wird die blosse Beobachtung zu den wichtigsten Ergebnissen führen können, wenn sie, um das nochmals kurz zusammenzufassen, nach bestimmtem Plane an verschiedenen Stellen über längere Zeit hin quantitativ durchgeführt wird.'*

(In all other cases, however, sheer observation may lead to the most important results if, to put it briefly again, it is pursued quantitatively according to a fixed plan in different places for a longer period.)

H. BREMER, 1926

[60] 'Entomologists are now beginning to realize that pests must be studied in relation to their environment if control is to be economically effected.'

A. H. STRICKLAND, 1953

[61] 'The problem to be solved may be briefly stated as follows: "To establish and demonstrate whether it is practical to cut the grain while it is still immature when you have a given quantity of rust infecting a province and a given degree of maturity of the grain".'

F. FONTANA, 1767

[62] 'It is quite certain that there is an epidemic meteorology.'

S. SMITH, 1866

During the past twenty years entomologists have developed the concept of the economic threshold of a pest, this is the severity of infestation at which control measures become economically rewarding. Epidemiologists are becoming interested, now that they see a way to disease and loss forecasting. The problem is to determine at what severity of infection and at what growth stage action should be taken, a problem first clearly formulated by FONTANA in 1767 [61].

### 3.3. METEOROLOGY AND PHENOLOGY

The importance of weather and climate in epidemiology has been recognized from the earliest written records, but a systematic study of relations between weather and epidemics started late. UNGER (1833) repeats the usual argument about cereal rust epidemics, speculates on unknown laws ruling the appearance of epidemics, and mentions atmospheric and cosmic influences. KÜHN (1858) discusses the *Beschaffenheit der Witterung* (medium term weather types) and the general telluric conditions. Apparently, telluric was used as opposed to cosmic, with reference to the then much studied natural electricity and earth magnetism.

TOZZETTI (1767) used daily weather records in an attempt to analyse the Tuscan wheat rust epidemic of 1766, and he distinguished various weather types (German: *Witterungen*), each lasting several days. He realized the importance of a cold winter to crop development and thus, indirectly, to the epidemic. During the century following Tozzetti, little serious work seems to have been done. A proposal by HLUBEK in 1847 (MAYER, 1952) to undertake this study which involved keeping regular weather observations found no response, probably because the scientists of that period were engaged in the decisive struggle over pathogenicity.

A detailed discussion on the relation between epidemics and climate came from the medical side [62] (SMITH, 1866); characteristically, it was a plea for cleanliness. The holistic trend starting around 1910 brought many hints on the usefulness or necessity of studying the environment [15] (HARDING, 1912; ORTON, 1914). Much attention was given to phenology, the study of periodical phenomena of plants and animals in relation to climate and weather. An early Phenological Observation Service (*Phänologischer Beobachtungsdienst*) was started in Germany in 1912 (WERTH, 1921). Phenological research intensified in Germany (BREMER, 1926; MORSTATT, 1921; STOLZE, 1955) and in the Netherlands (MILLER & O'BRIEN, 1957) during the twenties. The objectives of phenological research with respect to epidemiology were to find correlative rather than causal-analytical relations between weather and disease outbreaks, and little thought was given to experimental approaches (BLUNCK, 1929; BREMER, 1926). Relations between weather and epidemics were finally established. A first attempt was probably a publication by LUTMAN in 1911, in which he related the presence and absence of *epidemics* of potato late blight to daily weather records over a twenty years' period (1891–1910). Of somewhat

later date are studies aimed at the identification of infection periods of *Plasmopara viticola* (e.g. ISTVÁNEFI & PÁLINKÁS, 1913) and *Phytophthora infestans* (LÖHNIS, 1924). VAN EVERDINGEN's (1926) publication on *Phytophthora infestans* and weather was typically a meteorologist's approach. Though the method used was correlative, crude and maybe even incorrect in the eyes of present epidemiologists, the Netherlands had a potato late blight warning system around 1933, with the full cooperation of the Royal Netherlands Meteorological Institute (MILLER & O'BRIEN, 1957). The 'Dutch Rules' have been in use for over 20 years. The rules necessitated special regional observation posts, in accordance with a German plea for 'field laboratories' (BLUNCK, 1929), but to the dissatisfaction of later officials. In the U.K. systematic studies of the correlative type have been done for several decades (B.M.S., 1940), and GRAINGER's disease phenology plots (1950) should be mentioned as a valuable post-war outcrop of the correlative approach. In the U.S., the Plant Disease Survey was extended as a World War II emergency and did useful work, and as a result a potato late blight forecasting service was started in the Upper Mississippi Valley in 1942 (LEACH, 1943).

[63] 'The writings of Hippocrates, Aristotle, and other philosophers of the Greek period contain material which is clearly ecological in nature. However, the Greeks literally did not have a word for it. The word "ecology" is of recent coinage, having been first proposed by the German biologist, Ernst Haeckel in 1869.'

E. P. ODUM, 1971

[64] 'In the fourth century B.C. Theophrastus accepted the idea that environment influences the incidence of plant diseases.'

J. COLHOUN, 1964

[65] 'We should turn even more to the advantages which accrue from the study of the effects of environment on disease.'

J. COLHOUN, 1964

[66] '*Die ökologische Forschung, die so viele Einzelfragen zusammenschliesst, setzt aber umfassende Kenntnisse der Pflanzenkrankheiten voraus. Sie wird daher am besten auf der Grundlage einer allgemeinen Pathologie betrieben.*'

(The ecological research, which brings together so many separate questions, requires, however, a comprehensive knowledge of plant diseases. It is therefore best done on the basis of a general pathology.)

H. MORSTATT, 1929

[67] 'In the opening address A. J. P. Oort described epidemiology as a branch of ecology dealing with ecosystems in which a predatory, parasitic or pathogenic relationship exists between an organism and its host.'

A. J. P. OORT, 1971

In: D. J. BUTT, 1972



On the occasion of the 50th anniversary of the American Phytopathological Society in 1958 a 'Symposium on epidemiology of plant diseases' was organized. One speaker, defining plant disease forecasting as applied epidemiology, developed inviting perspectives for epidemiologists [19] (MILLER, 1959). At the 50th annual meeting it was decided to establish a temporary Advisory Committee in Agricultural Meteorology, to act as liaison between the American Phytopathological Society and the American Meteorological Society (A.P.S., 1959). In 1961, the committee became a subject matter committee in organizing a series of symposia together with sister societies, e.g. (VAN ARSDEL, 1962; A.P.S., 1961, 1966):

1960 – Weather and plant disease

1961 – Weather and organisms

1962 – Weather observations for plant pathology

1963 – Requirements and interpretations of biometeorological observations

1966 – Plant disease epidemics – analysis and implications

Except for some belated support to phenology (MÜLLER, 1957; STOLZE, 1955; UHLIG, 1954), it was realized in the fifties that phenology as such had little to offer epidemiologists, and that more comprehensive studies should be undertaken. A valuable approach was contributed by E. C. LARGE (1953), who developed a potato late blight warning system based on information from a large number of synoptic weather stations, a network of treated and untreated plots, using refined statistical methods in a correlative approach. A difference from earlier systems was that he could make use of epidemiological knowledge gained by experimentation.

### 3.4. ECOLOGY

A good and wide definition of ecology is 'environmental biology' (ODUM, 1971). HIPPOCRATES, father of epidemiology, evidently had a fair notion of what is now called ecology [63]. The word ecology was coined and published by E. HAECKEL in 1869, though it had been used in a similar way by THOREAU in private correspondence in the year 1858 (KORMONDY, 1969). Interest for the 'ecological' approach, as it is now fashionably labelled, reached peaks in periods with holistic tendencies, such as the periods 1910–1930 and 1960–today [64, 65] (COLHOUN, 1964). In 1929, MORSTATT regarded ecology as a part of phytopathology [66]; in 1971, OORT characterized epidemiology as applied ecology [67] (BUTT, 1972).

Epidemiology is evidently related to ecology; a great deal of phytopathological practice was and still is merely applied ecology. In recent years has the term ecology appeared frequently in phytopathological writings (BAKER & SNYDER, 1965; KERLING, 1969; PREECE & DICKINSON, 1971; SCHIPPERS, 1973), often used correctly, but sometimes used for publicity and/or funding only. In plant

virus studies, the term ecology has come into use for what can also be called epidemiology of plant virus diseases (MATTHEWS, 1970). In this context it is interesting to see how repulsive the term ecology was to a prominent plant pathologist in 1929 [68] (WHETZEL, 1929), and how attractive it was to two equally prominent phytopathologists in that same year 1929 [69] (FISCHER & GÄUMANN, 1929). GÄUMANN's famous *Pflanzliche Infektionslehre* (1946) is a continuation and elaboration of his earlier contribution to ecological plant pathology. In a recent definition a close link was made between epidemiology and ecology [70] (ZADOKS, 1972).

Only rarely has man been regarded as part of the anthropogenic ecosystem in which epidemics can rise and fall. Dutch authors have tried to give man, the

- [68] 'Pertinent objections can be raised not only to each of these (the terms "environmental factors", "ecology" and "epidemiology") in particular but more cogently to the lack of uniformity and consistency in the naming of this phase of the subject. We have long had at hand the etymologically consistent term epiphytotic to designate the destructive occurrence of a disease. We shall avoid the inconsistent implication of epidemiology and the embarrassment of the already preempted "ecology" by the rational coinage and use of epiphytology in this connection.'

H. H. WHETZEL, 1929

- [69] '*Die folgende Darstellung soll sich nun speziell mit den parasitischen Pilzen und ihren besonderen Lebensbedingungen und Beziehungen zur Umwelt beschäftigen, also, um der dafür gebräuchlichen Ausdruck zu verwenden, mit ihrer Biologie oder genauer Ökologie.*'

(The following presentation will now deal especially with the parasitic fungi and their specific conditions of life and relations with the environment, thus, to apply the usual term for this, with their biology or, more accurately, ecology.)

E. FISCHER & E. GÄUMANN, 1929

- [70] 'Epidemiology of plant diseases is a specialized form of ecology which deals with populations of pathogens ravaging populations of plant hosts.'

J. C. ZADOKS, 1972

- [71] '*Stelt men de factoren die bij de fytopathologie een rol spelen als een vijfhoek voor met de plant, het pathogeen, het abiotisch milieu (klimaat en bodem), het biotisch milieu en de mens als hoekpunten, dan kan men een of enkele van deze hoekpunten als uitgangspunt kiezen voor het onderzoek.*'

(If we represent the factors which play a role in plant pathology as a pentagon with the plant, the pathogen, the abiotic environment (climate and soil), the biotic environment, and man as the corners, then one can choose one or more of these corners as a starting point for research.)

A. J. P. OORT, 1966

- [72] 'This uniformity derives from powerful economic and legislative forces.'

COMMITTEE ON GENETIC VULNERABILITY, 1972

changer of things, his place in the ecosystem (KERLING, 1953; OORT, 1966, 1968). [71]. Following a different line of thought, an American Committee (COMMITTEE ON GENETIC VULNERABILITY, 1972) investigating the vulnerability of crops indicated man and man-promoted uniformity as the major cause of vulnerability of crops to epidemics and pests [72].

### 3.5. QUANTITATIVE METHODS (INCLUDING MATHEMATICS AND STATISTICS)

In medicine, simple methods of descriptive statistics have been applied since the days of JOHN GRAUNT and WILLIAM PETTY, who analysed the London Bills of Mortality (BAILEY, 1957; GALE, 1959). About two centuries later, a simple numerical analysis of families using water from various sources helped to solve the problem of cholera control in London (MACMAHON & PUGH, 1970), in a time when the etiology of the disease was not yet known.

The step from descriptive statistics to experiments was made just after 1900, when FLETCHER (1907) performed his famous experiment on the possible cause of beri-beri disease in the Kuala Lumpur Lunatic Asylum. The scope for experimentation in medical epidemiology is limited, for evident ethical reasons.

The step from descriptive statistics to analytical mathematics was taken at about the same period. HAMER in 1906 considered that the course of an epidemic will depend *i.a.* on the number of susceptibles and the contact-rate between susceptibles and infectious individuals (BAILEY, 1957). ROSS (1911) went deeply into the mathematical aspects of malaria epidemiology. All deterministic theories go back to the simple mathematical assumptions of HAMER, and the same can be said for the stochastic theories. A break-through in the stochastic approach was BAILEY's thorough discussion in 1957. Stochastic methods have little been used in phytopathology, firstly because plant pathologists usually deal with large numbers of units that allow for deterministic handling, secondly because stochastic methods are very difficult. Recently, stochastics, or should one say 'pseudo-stochastics', have been applied in simulation models (see below). Analytical models for population growth were first published by VERHULST (1845). His 'logistic' equations have been applied again by PEARL & REED (1920) and YULE (1925). Typical analytical solutions have been tried from time to time (e.g. GOFFMAN, 1966).

A side-step was made by the phytopathologist LARGE (1952), who compared growth curves of epidemics of *Phytophthora infestans* in the U.K., using the S-shaped cumulative normal curve for purposes of abstraction. Logistic equations were first applied in phytopathology by VAN DER PLANK in his chapter on the 'Analysis of Epidemics' in HORSFALL & DIMOND's 'Plant Pathology', 1960. ZADOKS (1961) used logistic equations in a study on *Puccinia striiformis* of wheat, and introduced a graphical method to correct for variable length of the latent period. VAN DER PLANK in his masterly book 'Plant Diseases, Epidemics and Control' (1963) elaborated widely on the logistic equation, giving a great variety of applications and describing a family of new equations all descending

from one simple mother equation [73]. By providing a solid theoretical foundation, VAN DER PLANK has given epidemiology its own identity as a specialism (1960, 1963).

In general, the statistical techniques applied in epidemiology are rather simple, as they are usually applications of the analysis of variance. Multiple regression analysis, applied in recent years (BUTT & ROYLE, 1974), has shown itself useful in finding important factors that determine or predict the future course of the epidemic, and eventually yield losses.

Quantitative epidemiology made its entry into medicine around 1910 (see above), into phytopathology in 1963 (HIRST, 1964). Computer simulation of epidemics (see below) is impossible without quantification. Tracing back the history of quantification we see LARGE's (1952) disease warning thresholds and GÄUMANN's (1946) generalized description of the growth and decline of epidemics. Further back there seems to be little worth noting until TOZZETTI, who in 1767 showed a clear perception of the steady multiplication of wheat stem rust, generation after generation, until such a severity was reached that every culm was damaged [74].

[73] 'This book is a landmark in the history of Plant Pathology, giving us for the first time a coherent and developed theory of plant epidemiology, a notable intellectual achievement.'

P. H. GREGORY, 1965

[74] 'But if, as happened in 1766, the Rust should be born very early, and found the Plants of the Wheat, and of the Oats, tender and sappy, and then time after time it should be born anew, and always in greater quantity, immense is the mischief which it causes, because it makes, so to speak, a pasture of the Wheat, and infests the Arteries to such an extent, that hardly any of them are left, capable of carrying the necessary nutriment to the ear.'

G. T. TOZZETTI, 1767

[75] 'Then we have the entrancing advances in meteorology and climatology to serve as prospecting tools in plant pathology, weather prediction and disease prediction, new thermistors and recording devices for weather variables, phytotrons.'

J. G. HORSFALL, 1959

[76] 'Taking to computers is generally regarded as a sign of maturity in a field of study, in much the same way as experimentation with tobacco and alcohol is a sign that one's children are growing up.'

P. M. A. BOURKE, 1970

### 3.6. NEW TECHNOLOGY

Epidemiologists are tool-lovers and tool-makers [75] (HORSFALL, 1959). HIRST was a pioneer; he designed a continuous volumetric spore trap and a dew balance (HIRST, 1952; 1957). This is not the place to review the countless spore traps, dew and leaf wetness recorders, rain splash simulators, etc. that epidemiologists have devised for their work. However, the impact of new technology is different from this now already classic type.

New technology boosts epidemiology (ZADOKS, 1974a). Epidemiologists have always been keen on measuring equipment of all kinds, especially on (micro-)meteorological equipment. Great advances were made recently by meteorologists, crop physiologists, and ecologists in multi-point data collection by means of a wide range of sensors, computer-compatible, with real time data processing, etc. Penetration of electronics into epidemiology, that has just started, will open up new avenues.

Phytopathologists were late in using the computer for their own purposes. In 1968, WAGGONER published his first paper on dynamic simulation of an epidemic by means of a digital computer. In the same year, at the First International Congress of Plant Pathology, the senior author discussed the results of computer simulation. Many papers have followed. Computer modelling of epidemics appeals to eager young phytopathologists, and epidemiology can no longer be thought of without computers. However, BOURKE's (1970) acid remark [76] is still valid, as is VAN DER PLANK's (1975) criticism.

Remote sensing encompasses all techniques which collect information on an object, here a diseased plant or crop, without touching it. A sensor collects information in analog or digital form and transfers it to an information carrier, e.g. photographic film or magnetic tape. The distance between sensor and object varies from c. 1 m to 1,000 km. Remote sensing, often taken to include computerized data processing, shows promise in disease detection, and disease and loss assessment. An early advocate of aerial photography in plant pathology was NEBLETTE (1927). The application of space-craft to biology (including crop protection) was reviewed recently (ZADOKS & FRINKING, 1974).

### 3.7. PLANT BREEDING AND EPIDEMIOLOGY

Plant breeding and epidemiology have deeply influenced each other; epidemiologists are only now beginning to realize how deeply. It is, therefore, too early to attempt to write a historical survey. Instead, some rather unrelated observations will be made.

Specificity of disease was well known, vide FRACASTORO's remarks [26]. TOZZETTI's statement that rye was not affected during the 1766 wheat rust epidemic in Tuscany must have been repeated many times in many places. DUHAMEL (1728) was probably the first to study experimentally the host range of a pathogen, *Rhizoctonia violacea* (see 2.3.2). DE BARY's comprehensive study

from 1853 may be regarded as a first attempt to explain or at least describe the phenomenon now indicated as 'host specificity'.

It is not so clear when the relative constancy throughout the generations of differences in resistance was first recognized. Evidently, such differences were already utilized by anonymous selectors throughout the centuries, and certainly in the 19th-century pre-breeding era. Generic, specific, and varietal differences in resistance were clearly recognized by ERIKSSON & HENNING (1896). They also recognized host specificity of strains within one parasitic species, and described *formae speciales* of cereal rusts with host specificity at the generic level. MARSHALL WARD in 1901 was aware of varietal differences in resistance among host plants, and attached some significance to 'disease-proof' varieties. But, curiously, SORAUER in his many publications around 1900 had not placed varietal differences in resistance and its utilization on his priority list. At that time, plant breeders had published little on resistance breeding. During World War I, finally, host specificity at the varietal level was found in the cereal rusts, and 'biologic forms', now called 'physiologic races', were identified (STAKMAN & PIEMEISEL, 1917).

The earliest resistance breeder found hitherto is MILLARDET (1891), who crossed *Vitis vinifera* with American vines to obtain resistance against *Phylloxera* (*Viteus*) *vitifolii* and *Plasmopara viticola*. In the U.S.A., ORTON (1900) started resistance breeding at the turn of the 19th century, and in Europe BIFFEN (1905) published on monogenic recessive inheritance of resistance against *Puccinia striiformis* in wheat. For nearly half a century resistance breeding in large parts of the world was strongly influenced by the St. Paul, Minnesota, school of thought, for better and for worse. JOHNSON (1961) wrote on 'man-guided evolution in plant rusts'. The resistance used during this period was mostly of the type now called 'vertical resistance' (VAN DER PLANK, 1963). Its impact, positive and negative, on epidemiology cannot yet be fathomed.

[77] 'It is something worth pondering, that in this Calamitous Year, Sowings of Rye only, or of *Segalato*, that is to say of Wheat and Rye, were immune from Rust, and I have understood that in the Valdinievole, those who had sown *Segalati*, had a very beautiful Crop, in which the wheat was the finest to be seen in Tuscany. The same thing happened in the *Vecciati*, that is to say Wheat sown along with Vetch. It is not so easy to render a reason, why Wheat growing seeded with Rye, or with Vetch, was not damaged by the Rust, while a Field of Wheat alone, standing between one of Rye, and one of Vetch, yielded scarcely any seed, and that the most miserable.

G. T. TOZZETTI, 1767

Hardly anything can be said about the epidemiological side-effects of breeding for agronomical characters as e.g. early ripening, tolerance to late sowing, short straw, high nitrogen response, tolerance to irrigation, or suitability for mechanical harvesting. The shortening of the vegetation period of winter wheat has certainly affected the epidemiology of *Puccinia striiformis* (ZADOKS, 1961), but to what extent cannot (yet) be said. Other side-effects of breeding for agronomic features desirable in themselves are well known as the 'green revolution's second generation of problems'.

As a final remark in this section, a historical support for the present day interest in 'multiline' or 'composite' varieties is presented. It was customary in Europe, as it is still in many parts of the world, to plant 'mixed crops', consisting of at least two species. TOZZETTI (1767) wrote that the wheat in the wheat-rye and wheat-vetch mixtures remained free of rust during the severe black stem rust (*Puccinia graminis*) epidemic on wheat in Tuscany, Italy, 1766 [77]. The record was based on hearsay evidence, and some embellishment may have taken place during the verbal transfers between observer and recorder, but certainly the wheat in the mixtures showed little infection and good yield in comparison with the wheat in the monocultures.

### 3.8. RETROSPECTIVE EPIDEMIOLOGY

Retrospective epidemiology is the description and analysis of an epidemic in the past, collecting all relevant information of which much was not available to contemporaneous scientists, and studying this critically with present-day knowledge of phytopathology, meteorology, etc. LARGE (1950) did fine work in his 'Advance of the Fungi', adding a touch of drama to his descriptions. BOURKE (1964) made an outstanding retrospective analysis of the 1845 potato late blight epidemic in Europe; he concluded that *Phytophthora infestans* must have been in Europe before that year. BOURKE's merit is his extremely critical use of unpublished records and reports, pamphlets, and other material that is difficult to locate.

## 4. BOTANICAL EPIDEMIOLOGY TEACHING

It seems to be a matter of course that epidemiological aspects used to be a normal part of phytopathological teaching (Table 4), but little evidence is available. In his 1860 lectures in Yale University, GOODRICH seems to have touched upon epidemiological problems (HORSFALL, 1969a). The teaching of plant pathology in the U.S.A. during the twenties, thirties, and forties was influenced by WHETZEL's ideas. He divided the discussion of each disease into the sections etiology and epiphytology (see 3.4.). The latter aimed at the study of

the life cycle rather than at the influence of the environment on the pathogen. The influence of such teaching without ecological thinking can hardly be overestimated; it may – at least in part – account for the relative neglect of epidemiology in the U.S.A. during the fifties.

Epidemiology as a subject worthy to be taught at Universities was highlighted during the 2nd International Congress of Plant Pathology, Minneapolis, 1973, during a Symposium on Epidemiology Teaching. In several universities curricula on epidemiology had been constructed recently or were in the make (ZADOKS, 1974b).

## 5. SUMMARY

5.1. Throughout history there have been brilliant men who, each within his own frame of reference, perceived parts of truth: HIPPOCRATES, FRACASTORO, DUHAMEL DE MONCEAU, TOZZETTI.

5.2. These men recognized epidemics and upheld a notion of their common causes. Often, the scientific establishment of their day did not accept their ideas: This situation remained so until far into the 19th century.

5.3. In the 19th century, medical thinking pervaded phytopathology. The culmination was the application of KOCH's postulates to plant pathogens, which is up to this very day a beloved topic among phytopathologists. Some feed-back of phytopathological thinking to medicine did occur. After 1945, botanical epidemiology turned again to medical epidemiology for guidance.

5.4. Medical epidemiology, which came into being in the 19th century, seems to have gone through three phases:

- a. A phenomenological phase without etiological knowledge, and serving also to find clues for etiology.
- b. An experimental phase serving mainly to find practical answers to problems.
- c. A theoretical phase meant e.g. to be of use to policy makers.

Phase *c* is of relatively recent origin and phase *a* has received new emphasis in recent times.

5.5. Botanical epidemiology, in which these three stages can also be recognized though less clearly, had no specific identity until the 1960s. Epidemiological thinking was submerged in the general trends of phytopathological thinking. In 1963 the appearance of an epoch-making book (VAN DER PLANK, 1963) and the occurrence of a specialized symposium with far-reaching scientific consequences mark the birth of botanical epidemiology as a specialism in its own right.

5.6. In some periods epidemiological thinking was more productive than in others. These were periods when a trend prevailed in the natural sciences that has been called holism. The mystical and misty holism of romanticism bore fruits after romanticism was dead. In the wake of the 19th century pos-



itivism, another wave of holistic thinking appeared at the turn of the century, stimulated by scientific internationalism. Between the two World Wars, it bore fruit in the form of disease forecasting systems. The third wave of holism (one is tempted to call it 'ecologism') became apparent in the 1960s. The tide of this holism rose high and in so doing it has engendered, among other things, botanical epidemiology.

5.7. The characteristics of this new science, which permit it to be ranked among the modern natural sciences, are its tendency towards abstraction (from individual diseases to groups of diseases), its design of an appropriate terminology, its quantification leading to statistical tests and predictions, its leaning towards theoretical concepts and models (from state to process), its manifold interdisciplinary relations, and its inclusion in teaching curricula.

5.8. The present study is a first attempt to write the history of botanical epidemiology. It is meant as a survey, an inventory of ideas in the ecological branch of phytopathology. The development of the concept 'epidemic' has been traced, and some aspects of the development of generic concepts such as 'epidemiology' and ancillary sciences have been indicated.

5.9. There was no opportunity to dig more deeply into the history of epidemiology either by studying manuscripts, letters, unpublished reports, pamphlets, and other primary sources, or by tracing the development of specific concepts (e.g. 'infection cycle', 'latent period') used as building-blocks in present-day epidemiology.

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## 6. POSTSCRIPT: THE DEVELOPMENT OF SPECIALISMS IN SCIENCE

It is a fascinating occupation to follow lines of thought until a new concept comes into being, which in turn starts to generate new lines of thought. As an activity this occupation is part of the Science of Science (to be called meta-science?), which has attracted certain attention recently.

In the foregoing treatise the birth of a new specialism, its evolution as a science in its own right, by congressional and other institutional activity, has been described. The birth of Botanical Epidemiology is by no means a unique event. A striking parallel is given by VAN DER WOUDE (1969): the development of Historical Demography as a science derived from history. In this case, the First International Congress on Historical Demography in 1950 could be chosen as a birth-date, or another significant date between 1945 and 1963. The parallel with epidemiology holds good, since in historical demography quantification and statistical testing of results are advocated, and in research emphasis has shifted from state to process. Relevance was acute in France, where the lack of population growth after World War II alarmed the authorities, who funded a research institute.

There are probably several such parallels, but they have not come to the attention of the authors.

## 7. TABLES

Table 1. Some important phytopathological dates up to World War I

Australia	1890	Committee of the Australasian Association for the Advancement of Science (MACALPINE, 1907).
Austria	1901	Kaiserlich-Königlich Landwirtschaftlich-bacteriologische und Pflanzenschutz-Station, Vienna, Director: K. KORNAUTH (BERAN, 1951).
Belgium	1894	Committee of the Royal Belgian Botanical Society, President: VAN BAMBEKE (ERIKSSON, 1901; SORAUER, 1894b).
Canada	1909	First laboratory of plant diseases (STEVENSON, 1959).
France	1888	La Station de Pathologie Végétale, Paris, Director: E. E. PRILLIEUX, tasks: extension and teaching (SORAUER, 1891c; WHETZEL, 1918).
Germany	1889	'Sonderausschusz für Pflanzenschutz' of the 'Deutsche Landwirtschaftliche Gesellschaft' (SCHLUMBERGER, 1949; MORSTATT, 1920).
	1891	21 Information Centres for plant protection (ERIKSSON, 1901; SCHLUMBERGER, 1949).
	1894	Institut für Pflanzenphysiologie und Pflanzenschutz, Land-

		wirtschaftliche Hochschule, Berlin, Director: A. B. FRANK (ERIKSSON, 1901; SCHLUMBERGER, 1949).
	1898	Biologische Abteilung für Land- und Forstwirtschaft (des Kaiserlichen Gesundheitsamtes), Berlin, Director: A. B. FRANK (ERIKSSON, 1901; SCHLUMBERGER, 1949).
Hungary	1896	Experimental Station for Plant Diseases, Magiar-Ovar, Director: LINHART (ERIKSSON, 1901).
Japan	1899	Section Plant Pathology, Imperial Agricultural Experiment Station, Tokyo (AKAI, 1974).
Netherlands	c. 1860	Parliament refuses grant for crop protection research (WITTEWAALL, 1864).
	1891	Nederlandsche Phytopathologische Vereniging.
	1894	Phytopathologisch Laboratorium 'Willie Commelin Scholten', private foundation, Amsterdam, Director: J. RITZEMA BOS (RITZEMA BOS, 1895a, 1906).
	1899	Phytopathologische Dienst, Amsterdam, Director: J. RITZEMA BOS (ANONYMOUS, 1900).
	1906	Instituut voor Phytopathologie, Wageningen, Director: J. RITZEMA BOS (ANONYMOUS, 1906).
Poland	1895	Phytopathological Committee of the Warsaw section of the Society for the Advance of Russian Industry and of Commerce, Chairman: A. SŁOŚAŃSKI (ERIKSSON, 1901; SORAUER, 1895).
Romania	1891	Phytopathological Station at the 'Scoală centrală de Agricultură și Silvicultură de la Herestreu', Director: G. MAIOR (SORAUER, 1891a).
Sweden	1890	Government grants Sw. Cr. 10,000 for a research project on cereal rusts (ERIKSSON, 1901).
Switzerland	1893	Formal proposal to Department of Agriculture to start a Phytopathological Station (SORAUER, 1893).
United Kingdom	1825	Scottish Cryptogamic Society, later Scottish Mycological Society (RAMSBOTTOM, 1963).
	1895	Mycological Committee (RAMSBOTTOM, 1948a, b).
	1896	British Mycological Society (RAMSBOTTOM, 1948a, b).
United States of America	1862	State Colleges of Agriculture (SMITH, 1962). Morrill Act (STEVENSON, 1959).
	1862	Department of Agriculture (STEVENSON, 1959).
	1871	T. TAYLOR appointed as phytopathologist U.S.D.A. (STEVENSON, 1959).
	1884	Committee on the Encouragement of Researches on the Health and Disease of Plants, of the American Association for the Advancement of Science (STEVENSON, 1959).
	1885	Hatch Act, ordering State Experiment Stations (SMITH, 1962). Section Mycology, in 1887 name changed into Vegetable Pathology, at U.S.D.A. (SMITH, 1962; WHETZEL, 1918).
	1902	American Mycological Society (RODGERS, 1952).
	1909	American Phytopathological Society (WHETZEL, 1918).
	1912	Plant Quarantine Act (HOWARD, 1927; SHEAR, 1913).
	1917	Plant Disease Survey (LYMAN, 1918).
U.S.S.R.	1896	Bacteriological Laboratory (KLEMM, 1941).
	1901	Central Laboratory of Plant Pathology, St. Petersburg, Director: A. JACZEWSKI (JONES, 1933; KLEMM, 1941).
	1907	Bureau of Mycology and Phytopathology, Director: A. JACZEWSKI (JONES, 1933).

Table 2. Foundation dates of phytopathological and related societies up to World War II

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1891	Nederlandsche Phytopathologische Vereeniging (Netherlands)
1896	British mycological Society (United Kingdom)
1908	The Quebec Society for the Protection of Plants from Insects and Fungous Diseases (Canada)
1909	American Phytopathological Society (U.S.A.)
1914	Société de Pathologie Végétale de France (France)
1920	Phytopathological Society of Japan (Japan)
1929	Canadian Phytopathological Society (Canada)

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Table 3. Starting dates of some phytopathological journals up to World War II

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1891	Zeitschrift für Pflanzenkrankheiten (Germany)
1892	Rivista di Patologia vegetale (Italy)
1895	Tijdschrift over Plantenziekten (Netherlands)
1896	Transactions of the British mycological Society (U.K.)
1907	Bolezni Rastenij (U.S.S.R.)
1911	Phytopathology (U.S.A.)
1913	Annales du service des épiphyties (France)
1913	La Revue de Phytopathologie (France)
1916	The Plant Disease Reporter (U.S.A.)
1917	Materialy po Mikologii i Fitopatologii (U.S.S.R.)
1919	Phytoprotection (Canada)
1921	Ochrana Rostlin (Czechoslovakia)
1921	Annals of the Phytopathological Society of Japan (Japan)
1924	Zaščita Rastenij (U.S.S.R.)
1925	Zeitschrift für angewandte Entomologie (Germany)
1925	Anzeiger für Schädlingskunde (Germany)
1926	Phytopathological Classics (U.S.A.)
1927	Boletín de Patología vegetal y Entomología Agrícola (Spain)
1929	Proceedings of the Canadian Phytopathological Society (Canada)
1930	Phytopathologische Zeitschrift (Germany)
1932	Zhurnal épidemiologii i mikrobiologii, Moskva (U.S.S.R.)
1935	Annales de l'Institut Phytopathologique Benaki (Greece)
1944	Annales cryptogamici et phytopathologici (Denmark)
1944	Boletim Fitosanitário (Brazil)

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Table 4. Some data on the beginnings of phytopathological teaching

Belgium	1920	D. VANHOVE, Supervisor-head of the Phytopathological Service was entrusted with the course on phytopathology at the State Agricultural College in Gent (VAN OYE, 1967).
Denmark	1883	E. ROSTRUP appointed as instructor in plant pathology. Kongelige Landbohøjskole, Copenhagen (Lector in 1889, Professor in 1902) (BUCHWALD, 1967).
Germany	1854	F. FLEISCHER read first lecture on plant disease, at the Agricultural College, Hohenheim (RADEMACHER, 1967). Institut für Pflanzenphysiologie und Pflanzenschutz, Landwirtschaftliche Hochschule, Berlin (SORAUER, 1894a).
	1921	First ordinary chair in phytopathology, E. SCHAFFNIT, Landwirtschaftliche Hochschule (Agricultural College), Bonn, Poppelsdorf (ZILLIG, 1948).
Hungary	1926	First chair in phytopathology. K. SCHILBERSZKY (UBRIZSY, 1966).
Japan	1873/6	F. M. HILGENDORF lectured occasionally on plant pathology (AKAI, 1974).
	1880	First course on plant pathology, Agricultural College, Tokyo (AKAI, 1974).
	1906	First chair of phytopathology (AKAI, 1974).
Netherlands	1894	J. RITZEMA BOS extraordinary professor in Phytopathology, Amsterdam.
	1906	Instituut voor Phytopathologie, Agricultural College, Wageningen, J. RITZEMA BOS ordinary professor (RITZEMA BOS, 1906).
U.S.A.	1860	C. E. GOODRICH delivered a lecture on Vegetable Pathology at Yale University during a 'course of lectures on agricultural subjects'. This is the first university lecture on plant pathology in the U.S.A. on record (HORSFALL, 1969a).
	1862	Congress accepts 'Morrill Act', leading to the institution of 'State Colleges of Agriculture', at which phytopathology was taught as part of the curriculum.
	1873	T. J. BURRILL teaches phytopathology at Illinois (STEVENSON, 1959).
	1907	First chair and department of plant pathology in U.S.A., at Cornell University (WHETZEL, 1918).
U.S.S.R.	c. 1898	Professor S. ROSTOVZEV teaches first course in phytopathology at the Agronomical Institute of Petrovsko-Razoumovskoie near Moscow (SCHROEVERS, 1923, p. 239).
	c. 1920	High School of Phytopathology and applied Zoology, Leningrad; one of the lecturers A. JACZEWSKI (JONES, 1933).
	1930	Institute for Zoology and Phytopathology, Leningrad (KLEMM, 1941).

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To keep this list within limits references have been restricted mainly to:

- reviews containing historical information,
- papers with original opinions relevant to the subject,
- early publications starting new developments, and
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