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Role of epidemiology in plant disease management

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Abstract
Plant disease epidemiology includes study of factors like temperature, moisture, humidity and precipitation etc. that are influencing the pathogen either positively or negatively depending on the requirement of pathogen for a particular kind of condition. These epidemiological studies are important for the management of the plant diseases as the obtained data can be processed and transformed into technologies for the management of pathogen.

Keywords: Epidemiology, monocyclic diseases, polycyclic diseases, infection rate

1. Introduction

Plant disease epidemiology is the study of disease in plant populations (Agrios, 2005) [1]. Plant disease epidemiology has been defined as the study of factors that affect the spread of disease in time and space (Madden *et al.*, 2007) [4], and there is an implicit understanding that most research ascribed to this sub-discipline of plant pathology is quantitative in nature and frequently characterized by models of varying complexity (Jeger, 2004) [31]. Plant disease epidemiology is often looked at from a multi-disciplinary approach, requiring biological, statistical, agronomic and ecological perspectives. Nonetheless, some aspects of theoretical epidemiology are conceptual in nature (Jeger, 2000) [19], and some authors consider epidemiology to have an early origin in efforts made long ago to control disease in populations of plants (Zadoks, 2001) [33]. Recently, epidemiology has also been used for predicting the effects of climate change on plant disease (Garrett *et al.*, 2006) [12]. Weather data generated from climate change models have been used to predict change in geographic range and/or severity of several diseases including rice leaf blast caused by *Pyricularia oryzea* (Luo *et al*., 1998) [22], oak disease caused by *Phytophthora cinimomi* (Bergot *et al.*, 2004) [5], grape downy mildew caused by *Plasmopara viticola* (Salinari *et al*., 2006) [26] and several forest diseases in France (Desprez-Loustau *et al.*, 2007) [10].

Methods of plant disease control were developed even before true nature of plant disease was understood. During early stages, 19th and early 20th century, the method of plant disease control were more a wishful thinking of plant pathologist. Epidemiological, studies generate lot of information on different aspects of disease development. This processed data helps in developing appropriate technology for plant disease management (Chaube and Pundhir, 2009) [8].

1.1 The Epidemiological Basis of Disease Management

Plant disease epidemics can be classified into two basic types, monocyclic and polycyclic, depending on the number of infection cycles per crop cycle. The early stages of a monocyclic epidemic can be described quite well by a linear model, while the early stages of a polycyclic epidemic can be described with an exponential model. Since we are concerned with keeping disease levels well below 100 per cent, there is no need to adjust the models for approaching the upper limit, and we can use the simple linear and exponential models to plan strategies. Examining these models, we can see that in both there are three ways in which we can reduce **x** at any point in the epidemic:

1. Reduce the initial inoculum (Q in the monocyclic model and x_0 in the polycyclic model). (Actually x_0 is the initial incidence of disease, which is proportional to the initial inoculum).
2. Reduce the rate of infection (R in the monocyclic model and r in the polycyclic model)
3. Reduce the duration of the epidemic (the time, t, at the end of the epidemic)

These, then, can be used as three major strategies for managing plant disease epidemics, and we can organize our plant disease control tactics under one or more of these overall strategies. Furthermore, by means of the model we can assess the quantitative impact of each strategy, not only by itself, but in its interaction with others.

a) The monocyclic model

$$x = \overset{\overset{1}{\downarrow}}{Q}\overset{\overset{2}{\downarrow}}{R}\overset{\overset{3}{\downarrow}}{t}$$

It is clear from the above model of a monocyclic epidemic that Q, R, and t have equal weight in their effect on x. A reduction in the initial inoculum or the rate of infection will result in a reduction in the level of disease by the same proportion at any time, t, throughout the epidemic. If **t** can be reduced (for example, by shortening the season), disease will be reduced proportionately.

b) The polycyclic model

$$x = \overset{\overset{1}{\downarrow}}{x_0}\, e^{\overset{\overset{2}{\downarrow}}{r}\overset{\overset{3}{\downarrow}}{t}}$$

- If **r** is very high, the apparent effect of reducing $\mathbf{x_0}$ is to delay the epidemic.
- If **r** is very high, x_0 must be reduced to very low levels to have a significant effect on the epidemic.
- Reducing r has a relatively greater effect on the epidemic than reducing x_0.
- Reducing x_0 makes good strategic sense only if r is low or if r is also being reduced.

It is easier to understand these concepts if we actually select different values for x_0 and r, plug them into the model, and graph the outcome. Clearly developing a sound disease management strategy requires enough knowledge of the biology of the pathogen and host to select the appropriate epidemiological model. It also requires at least "ball-park" estimates of the model parameters and the magnitude of the impact of each specific tactic on the initial inoculum or the apparent infection rate. Failure to adopt such a quantitative approach can lead to some embarrassing or even very costly errors.

2. The Traditional Principles Revisited

To make the conceptual leap from disease control to disease management, the traditional principles can be modified by fitting them as tactics within each of the three major disease management strategies and by slightly changing the wording to reflect the quantitative impact of the action rather than an absolute effect:

a) Tactics for the Reduction of Initial Inoculum

- **Avoidance:** reduce the level of disease by selecting a season or a site where the amount of inoculum is low or where the environment is unfavorable for infection
- **Exclusion**: reduce the amount of initial inoculum introduced from outside sources
- **Eradication:** reduce the production of initial inoculum by destroying or inactivating the sources of initial inoculum (sanitation, removal of reservoirs of inoculum, removal of alternate hosts, etc.)
- **Protection**: reduce the level of initial infection by means of a toxicant or other barrier to infection
- **Resistance**: use cultivars that are resistant to infection, particularly the initial infection
- **Therapy**: use thermotherapy, chemotherapy and/or meristem culture to produce certified seed or vegetative planting stock

b) Tactics for the Reduction of the Infection Rate

- **Avoidance:** reduce the rate of production of inoculum, the rate of infection, or the rate of development of the pathogen by selecting a season or a site where the environment is not favorable
- **Exclusion**: reduce the introduction of inoculum from external sources during the course of the epidemic
- **Eradication:** reduce the rate of inoculum production during the course of the epidemic by destroying or inactivating the sources of inoculum (roguing)
- **Protection**: reduce the rate of infection by means of a toxicant or some other barrier to infection
- **Resistance**: plant cultivars that can reduce the rate of inoculum production, the rate of infection, or the rate of pathogen development
- **Therapy**: cure the plants that are already infected or reduce their production of inoculum

c) Tactics for the Reduction of the Duration of the Epidemic

- **Avoidance:** plant early maturing cultivars or plant at a time that favors rapid maturation of the crop
- **Exclusion**: delay the introduction of inoculum from external sources by means of plant quarantine

3. Uses of Epidemiology in plant disease management (Chaube and Pundhir, 2009) [8]

1. The monocyclic disease (loose smut of wheat and wilts) and polycyclic diseases (rust, powdery mildew, and late blight of potato) should be given different treatment.
2. The information about source of primary inoculum and amount is vital as it can help us in forecasting disease and proper methods can be employed for disease management.
3. Information about potential for variability in pathogen population can help in adopting suitable breeding strategies, e.g. management of late blight of potato or wheat rust, with high chances of new races, should emphasized on development of horizontal resistance.
4. The economic threshold levels, once established may justify the action to be taken for disease management.
5. Field management of a disease on resistant crop cultivars will require much less fungicide use as compared to susceptible cultivars.
6. The behavior of vector populations can be effectively utilized to control plant diseases. This has been demonstrated in case of potato viruses and stewart’s corn wilt.
7. Disease forecasting can help in adopting the appropriate measures, which can help in reducing pesticides use without risking crop health.
8. Fungicides should be used judiciously for plant disease management. Contact fungicides are effective only as prophylactic. The systemic fungicides can be used for eradicative and curative action.

9. All possible information about pathogen and disease should be used for developing IPM schedule keeping local conditions in mind.

4. Managing Disease through Health of Planting Material

Epidemiology has had impact on disease management is in production of seed with reduced or no pathogen incidence. The use of healthy seed may appear of limited importance within a discussion of epidemiology, since it generally involves only one strategy for managing disease in the subsequent plant generation, that of limiting initial inoculum. Furthermore, inoculum thresholds have been established based epidemiological studies and models predicting disease transmission based on critical factors such as weather and cultural practices (Gitaitis and Walcott, 2007) [13]. Most epidemiology work in seed health has focused on specialized seed production systems and it would appear that very little epidemiology, theoretical or experimental, has been done for strategic or tactical management of seed borne diseases where seed is produced on the farm, which is particularly the case in developing countries. There is a long history of using virus-free planting material to control Cassava mosaic virus disease in Africa. The case of (sexual) seedborne diseases, significant efforts in theoretical epidemiology

have been applied to the problem of disease spread within multi-seasonal production units of vegetatively propagated crops, including the effects of management tactics, such as roguing (Jeger *et al.*, 2004; van den Bosch *et al.*, 2007) [20, 24].

5. Managing Virus Diseases

Many of the diseases affecting planting material (mentioned above) are caused by viruses, but the epidemiology and management of virus diseases *per se* has often been viewed separately within plant pathology (Jeger, 2000) [19], and regular symposia on plant virus epidemiology are organized by the Plant Virus Epidemiology Committee of the International Society of Plant Pathology. Plant virus diseases provide some very interesting case studies for linking epidemiology (in a broad sense and predating the use of the term) and disease management. Management of beet curly top virus using knowledge of the virus and vector predates the emergence of theoretical disease epidemiology by decades. This disease virtually wiped out beet production in the Salinas valley of California at the end of the 19th century, and was eventually managed by applying knowledge about host resistance and vector biology. Subsequently, a complex of Beet yellows virus and Beet western yellows virus were controlled by several tactics including a beet-free period in the Salinas valley (Wisler & Duffus, 2000) [32].

6. Managing Disease Based on Knowledge of Spatial Structure of Disease

Diseases intensity can increase over time due to the spread of pathogen propagules at different geographical scales. When inoculum is spread over large areas, this process is generally considered as inoculum dispersal. Local dispersal of inoculums usually results in a disease gradient. Knowledge about these processes can contribute to better understanding of the epidemics and ultimately to better disease management, although this is one area where a particularly poor linkage between generation of knowledge and subsequent field implementation has been documented (Jeger, 1999) [18]. Nonetheless, below are some examples of how knowledge of pathogen dispersal has been applied, with special emphasis on the management of citrus canker in Brazil.

Gradient studies have also been used for a number of other applications including:

1. Detection of sources of inoculum (e.g., cull piles) of *Phytophthora infestans* in potato in the Netherlands (Zwankhuizen *et al.*, 1998) [34].
2. Definition of isolation distances for peach trees and roses to avoid spread of powdery mildew
3. To generate hypotheses about the mechanism of dispersal of a pathogen (Fitt *et al.*, 1987) [11].
4. To make inferences about the etiological agent of a unknown disease, as for example in the case of Citrus Sudden Death (CSD) where a biological agent was proposed based on the disease gradient (Bassanezi *et al.*, 2003) [4].
5. To assess the efficacy of disease control measures, as in the case of witches broom of cacao, where a flat disease gradient was indicative of ineffective disease control (Alves *et al.*, 2006) [2].

7. Managing Disease Based on Pathogen Phenology – Ascochyta Blight in Chickpea

Epidemiological studies on pathogen biology were used to develop reliable and cost-effective management strategies. Under environmental conditions conducive to the pathogen, a healthy field may become severely diseased over a short period of time following ascospore discharge. Adequate disease management can be achieved by application of prophylactic sprays, or by initiating spraying when the disease is still at a low level. Thus, combating the primary infections originating from airborne ascospores was found to be the key to acceptable, season-long disease suppression wherever the teleomorph stage plays a significant role in *D. rabiei* epidemiology. As the time of disease onset varies from year to year and in different environments, a tool for predicting the time of pseudothecia maturation and ascospore discharge was needed (Shtienberg *et al.*, 2005). Studies conducted under controlled environments indicated that temperature and moisture (wetness) are the key factors leading to pseudothecia formation and maturation in *D. rabiei*. This information was used to develop empirical models aimed at predicting the influence of temperature and interrupted wetness on maturation of *D. rabiei* pseudothecia (Shtienberg *et al.*, 2005).

8. Managing Disease Based on Modeling the Time of Infection – Fire Blight in Pears

Investigations into the climatic factors influencing fire blight infections, with a view to possibly predicting of epidemics, were initiated in the 1920s and warning systems were developed by numerous workers from different countries. All models attempted to predict the occurrence of infection events based on empirical analyses of temperature and wetness duration. Some of the models were extensively examined and proved accurate in their country of origin, for example, MARYBLYT in northeastern USA (Steiner and Lightner, 1996), BIS in England (Billing, 1996), Cougarblight in northwestern USA (Smith, 1993) and FBCA in Israel. Occasionally the models performed adequately in alternate locations. Use of these systems assisted in timing the application of bactericides and early pruning of newly infected tissues (Shtienberg *et al.*, 2003). In Israel, use of the local system, FBCA, greatly reduced risk imposed by the pathogen on the pear industry. The system is extensively used by Israeli growers and after its introduction, severe fire blight outbreaks were not recorded and there was a steady increase in the area of pear plantation in the country.

9. Transferring Epidemiological Knowledge to End Users

9.1 Industrialized Countries: Use of Decision Support Systems

Growers need assistance in incorporating existing knowledge into their decision-making procedures. Decision support systems (DSS) are the tools by which complex knowledge can be formulated in a “user-friendly” way. Numerous DSS have been developed to help farmers improve their use of fungicides and make other disease management decisions (Lynch *et al.,* 2000) [23]. DSS for fungicide use in control of potato late blight (*P. infestans*) has been the focus of much activity by both government and private organizations in Europe where the disease has become more difficult to manage in the last two decades (Hannukkala *et al.,* 2007) [15]. There are other examples of DSS that have enjoyed wide adoption. Apple scab is a fungal disease caused by *Venturia inaequalis* that affects apples in several parts of the world. In Brazil, for example, a DSS based on meteorological variables was developed to predict periods favorable to the establishment of infection in apple trees. Whenever these periods are identified, fungicides should be sprayed to protect plants. A network of 8 meteorological weather stations was established in Santa Catarina state, Brazil, and daily issues of “infection risk” are broadcast by the media (TV, radio, e-mail, fax and telephone). The system was implemented in 1981 and is widely used in the apple growing regions of Santa Catarina for improved use of fungicides (Caramori *et al.,* 2002) [7]. Integrated IT approaches will undoubtedly provide opportunities for scientists to improve the utility of models, as these programs are also designed as feedback mechanisms for research (Isard *et al.,* 2006) [6]. For example, the DSS late blight community in Europe (described above) is striving to update the models to incorporate changes in pathogen population structure (Hadders, 2008). One of the objectives of the EUCABLIGHT project was to standardize and collate data on pathogen and host for use in model parameterization within DSS (Hansen *et al.,* 2007). The DSS structure allows for identification of indirect effects of epidemiology on disease management via different impact pathways. For example, studies on relative importance of different inoculum sources of *Phytophthora infestans* (Zwankhuizen *et al.,* 2000) [35] have been used in the development of regulations on the amount of disease allowed in fields and on management of potato cull piles (Cooke *et al.,* 2008) [9].

9.2 Developing Countries: Farmer Field Schools

There are some cases, however, when epidemiological knowledge has reached resource-poor farmers in developing countries. Generally, these have relied heavily on principles of knowledge management theory and adult pedagogy to enhance knowledge exchange, and have involved simple epidemiological principles rather than sophisticated modeling. One knowledge exchange mechanism that has been widely used with apparent success is the farmer field school (FFS). The FFS uses discovery based learning methods to improve the farmers’ agro-ecological knowledge, and their capacity to make decisions (van de Fliert *et al.,* 2002) [30]. Usually, a group of 20–25 farmers form a FFS, participating in weekly meetings during a whole cropping cycle. In the 1980’s the FAO organized a concerted action in Southeast Asia to improve rice production with FFS as a component. It is estimated that in Asia, FFS were implemented in more than a dozen countries, such as Thailand, Indonesia, Bangladesh, Laos, Malaysia, Nepal, Philippines, Sri Lanka, Vietnam and others, where the goal was to transfer knowledge regarding the development of plant disease epidemics in rice (Bartlett, 2005) [3].

9.3 The Role of Market

The influence of the consumer on farmer practice relative to pest and disease management use is also affecting farmers in developing countries. Ironically, however, this has occurred primarily through the export market, such that it is consumers in the industrialized countries affecting producers in the developing countries. This occurs via exported organic products and also through global trade regulations, which are exerting pressure on growers of exporting countries to adopt standards of good agricultural practices (GAP). Consequently, for these sectors, epidemiologically-based information has become more important and there are incentives to build mechanisms for effective farmer capacity building. For instance, in order to be a certified GAP exporter, restrictions on the number of fungicide sprays may apply. Bar-codes allow tracking the product back to its origin and to all records of cultural practices that were used. In Brazil, this has been implemented in citrus, mango, papaya, banana, and apple orchards, as well as in strawberry, grapes, processing tomatoes, and melon fields, among other crops (www.agricultura.gov.br). Unfortunately, the complicated requirements for GAP certification often leave small-size famers out of the picture (Ogambi, 2006) [25].

10. Conclusion

Overall, it would appear that one’s appreciation of the link between epidemiology and disease management is in part dependent on the definition of the science. The impact of epidemiology has developed from several types of theoretical or empirical research, including disease dispersal gradients, the pathogen life cycle, and the driving factors of weather on disease development (e.g., DSS for fungicide sprays). Plant disease epidemics are dynamic processes and changes in any of the determinant factors can compromise the efficacy of management practice. A classical example is the variation in populations of plant pathogens, as variants resistant to chemicals or capable of overcoming disease resistance genes constantly represent a major threat to disease management. The host plant population can also change and interfere with control actions, as for example the introduction of new varieties in a given region. Different crop systems (organic, conventional, hydroponics, etc.) in new agricultural frontiers can also introduce variation in established practices. Additionally, regulatory and/or market actions can change the portfolio of chemical compounds available to growers in a country. Thus, lack of constancy in factors affecting disease management requires continuous exchange between epidemiologist and practitioner.

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