4.1 DISEASE EPIDEMIOLOGY

Fact Sheet Objectives

- Explain how the cycle of infection and multiplication by plant pathogens leads to damaging disease epidemics in crops
- Explain the dynamics of epidemics and how they can be quantified and predicted
- Describe how epidemics are affected by disease control methods, with a particular focus on fungicidal control

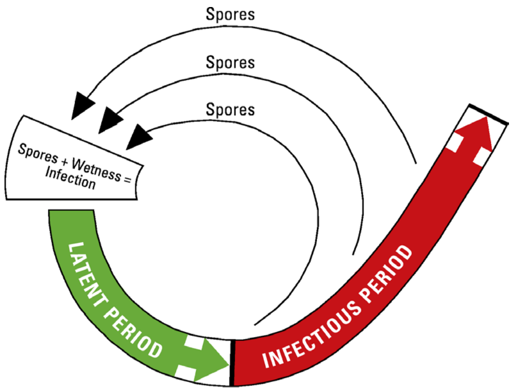

Figure 1. The infection cycle of fungal pathogens

***Infection efficiency** is the proportion of deposited spores that successfully infect the host plant. Epidemics develop most rapidly when infection efficiency approaches its maximum value of 1. This occurs when weather conditions are favourable, host susceptibility is high or there is no fungicide protection.*

Disease is a three-way interaction

Disease is an interaction between:

1) a virulent plant pathogen (disease-causing organism),

2) a susceptible host plant, and

3) environmental conditions favourable for infection.

The pathogen and the disease are two distinct things; pathogens cause disease and; the disease is the way the host plant and the pathogen interact.

A disease epidemic is a change in the amount of disease in a crop over time. Epidemics are dynamic and behave in characteristic ways that can be predicted, allowing diseases to be effectively managed.

Why does disease suddenly appear?

Fungal (or bacterial) pathogens are always present in every crop, actively going through their infection cycle and causing disease (figure 1).

- An epidemic occurs when conditions allow the rate of multiplication (infection and spore production) to increase above the level where the pathogen is just maintaining itself.
- Even under the most favourable conditions, damaging disease usually does not result from a single infection event, but occurs after the pathogen has undergone several cycles of multiplication.
- Disease can be first noticed when a threshold of detection is reached. This threshold is often between 0.1% and 5% incidence, but varies according to the experience of the observer and the sampling procedure being used.

  A several thousand-fold increase in disease may have occurred within a crop prior to disease detection. This means that epidemics start well before they are detected. Because disease can multiply very rapidly the cycle that takes an epidemic through the detection threshold, say from 0.1% to 10% incidence, may appear to happen very suddenly. The infection that results in such an increase may have occurred weeks earlier, but gone unseen until the end of the latent period.

Epidemics have momentum

Once started, an epidemic cannot easily be stopped because latent disease gives continuity to an epidemic during unfavourable conditions. Epidemics continue to develop during the latent period, even though disease may not be visible.

- During an epidemic, many infection cycles are occurring at once, so both latent and infectious disease are always present. If weather is favourable for infection, or fungicide protection is lacking, new infection can occur at any time.
- To stop an epidemic, weather unsuitable for infection would have to continue for an interval equal to one latent period plus one infectious period, i.e. many weeks. A few days of unsuitable weather will, however, slow an epidemic down, as will fungicide applications.
- The momentum that epidemics have makes them very difficult to stop with “fire fighting” fungicide applications after disease is well established.

__Latent period__ is the time between spores landing on the host and the production of new infective spores from diseased tissue.

It includes spore germination, host penetration, pathogen growth within the tissue and the start of new spores being produced.

Epidemics occur faster when the latent period is short, because the infection cycle occurs more frequently. Disease is often invisible during the latent period.

The latent period is longer at cooler temperatures. For some pathogens high relative humidity or wetness is required at the end of the latent period to stimulate spore production (e.g. grape downy mildew). Minimum latent period for most fungal pathogens is 10 days and is less than 4 days for bacterial diseases, depending on temperature.

During the latent period the pathogen is not affected by the weather and a long latent period allows the pathogen to survive adverse conditions.

__Infectious period__ is the period when infected tissue produces spores that can cause new infections. It starts at the end of the latent period. Epidemics proceed faster when the infectious period is longer because more inoculum is produced from each lesion. For most diseases it lasts for several months and ends when diseased leaves, fruit or twigs fall or are removed from the plant. Some pathogens need living host tissue to sporulate (e.g. powdery and downy mildews) whereas others can continue to sporulate after the plant tissue has died (e.g. Botrytis).

Fungicidal control of epidemics

Fungicidal control is only one of several possible approaches to disease management. However, fungicides have become the most cost-effective approach for many diseases and many crops could not be economically produced without fungicide inputs:

- Protectant fungicides act at the plant surface by preventing spore germination.
- Systemic fungicides move into the plant tissue and inhibit the pathogen within the tissue for up to a few days after infection (curative or eradicant activity). Most systemic fungicides are also protectants, or are used in mixture with protectants for fungicide resistance management reasons.
- Antisporulant fungicides prevent sporulation. Most protectant and curative fungicides are also antisporulants.
- The distinction between protectant, curative and antisporulant activity is much less important, epidemiologically, than it is given credit for. Prevention of infection and prevention of sporulation have an equivalent effect in slowing an epidemic.

***Spore production rate** is the number of new spores produced each day from each lesion. Epidemics proceed faster when the spore production rate is high.*

Seasonal Disease Cycle

Describes the seasonal development of the pathogen and its interaction with the host plant. It consists of overwintering, primary infection and secondary infection. Two components are epidemiologically important:

***Primary inoculum** consists of fungal spores or bacterial cells that cause the first infection of new tissue from the overwintering stage of the pathogen. Disease that results from primary inoculum is called primary disease.*

***Secondary inoculum** consists of fungal spores or bacterial cells resulting from primary disease and also from subsequent secondary disease. Disease epidemics are usually caused by successive cycles of secondary infection. As epidemics progress, the large amount of secondary inoculum that is produced usually makes primary inoculum rapidly become unimportant.*

Systemic fungicides are somewhat different, because they affect the fungus within the plant tissue. However their "reach back" activity only affects the first part of the latent period and for most of their latent phase most pathogens are protected from fungicides by being within the host tissue.

- Epidemics are most effectively slowed by:
  - Modern fungicides, which have greater activity than older fungicides.
  - Full fungicide application rates.
  - Frequent fungicide applications.
- Although more fungicide is better for disease control, this must be balanced against environmental and consumer requirements. Imperfect fungicide application technology means that the pathogen will always partially escape the effects of fungicide applications.

Sources of inoculum and disease spread

Fungal and bacterial pathogens produce vast amounts of inoculum (fungal spores or bacterial cells) from infected plant parts.

- Most inoculum dispersal occurs over short distances of only a few metres; i.e. dispersal gradients are very steep. The primary and secondary inoculum that drives epidemics is almost always produced within each orchard block. Spread of inoculum between blocks occurs only slowly.
- It is not possible to define exactly how far inoculum will spread. Most travels only a small distance, but a small proportion may travel many kilometres, depending on spore type and weather conditions.
- Some fungal pathogens produce "dry" spores (e.g. powdery mildews and *Botrytis*) that are blown by wind. These have the potential to spread many kilometres in dry, windy weather. Others produce "wettable" spores that are released and dispersed by rainwater, dew or irrigation. These can travel several metres in wind-blown splash droplets. Bacterial diseases are also spread by water. Ascospores of Apple Blackspot and European Canker are released by rain and are then spread by wind.

Pathogens that colonise dead tissue

Some fungal pathogens can saprophytically colonise and sporulate in/on dead plant material and can multiply in the orchard before they infect living tissue (e.g. fungal fruit rot pathogens like *Glomerella, Botryosphaeria* and *Botrytis*).

- These pathogens often have complex disease cycles, involving several types of dead material from various plants. Their biology is often poorly understood because the saprophytic phase is difficult to observe. The distinction between primary and secondary inoculum for these pathogens is unclear.
- These pathogens may not produce an epidemic on leaves or fruit in the orchard, but only appear as fruit rots in storage. The quantity of inoculum that builds up saprophytically within the orchard determines the incidence of infected fruit.
- Bitter Rot of apples and Botrytis Bunch Rot of grapes may be saprophytic during the early part of the growing season. However, when fruit begin to ripen they cause infection with secondary sporulation and an epidemic can occur that is driven by large amounts of secondary inoculum.

How Different Disease Control Strategies Affect Epidemics

- **Host plant resistance** makes all epidemiological parameters less favourable for epidemic development. Resistant varieties are the ultimate disease control solution, so long as the pathogen does not change and break down the resistance. Partial resistance, making epidemics develop a little slower, is extremely valuable, along with fungicides, in an integrated disease control strategy.
- **Sanitation** reduces primary inoculum by removing plant material that carries disease (e.g. removal of apple leaf litter for black spot management, pruning out shoots infected by European Canker, reduction of Botrytis by removing pruned canes from vineyards). Sanitation delays an epidemic by causing the pathogen to go through more infection cycles before a damaging disease level is reached.
- **Environment modification** reduces infection efficiency (e.g. leaf plucking of grapevines to reduce botrytis risk).
- **Fungicidal control** reduces infection efficiency and may also increase latent period, decrease infectious period and reduce spore production rate, depending on the type of fungicide.
- **Biological control** agents, if effective, reduce the pathogen's infection efficiency and may reduce spore production rate.
- **Plant defence elicitors** decrease infection efficiency and may increase latent period.

Summary

- Disease is an interaction between a pathogen, its host plant and environmental conditions. We know that prevention of crop losses due to disease is about management of this interaction. However, more effective and reliable disease control can be achieved through an understanding of the dynamics of disease epidemics.
- Epidemics have an identity of their own and a set of characteristics that makes them quite predictable.
- Epidemics start before disease can be detected and once started, they have momentum that makes then difficult to stop. Fungicides applied early, before disease appears, are more effective than those applied after disease has become obvious.
- Effective disease management therefore requires applying fungicides to control disease that cannot be seen.
- Understanding that a substantial part of epidemic development occurs as latent disease, which is protected from adverse weather and from fungicidal control, is important in understanding that fungicide applications can only slow and not stop the progress of disease epidemics.

Further information

Disease Forecasting: Factsheet 4.2 in this series

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