

20

ASSESSMENT OF DISEASE AND EFFECTS ON YIELD

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20.1 Introduction

Assessment or measurement of disease is the basis of epidemiology which is the study of disease at the level of populations of pathogens and hosts. It is also the basis of the study of the effects of disease on crop yield and of disease forecasting (Chapter 19), which involves the prediction of the amount of disease that is likely to occur at some time in the future.

It is usually not sufficient to determine whether a disease is present or absent. The critical information required is the amount of disease that is present. Disease often has to exceed a certain threshold before it reduces the yield of a crop. Small amounts have little effect on yield and the disease may not be worth controlling. The amount of disease is measured as the proportion of the crop population (counted as individual plants or branches or leaves etc.) that is infected (disease incidence) or the proportion of the area of a plant or plant organ (e.g. leaf area) that is affected (disease severity). In some cases, the proportion of leaves or branches infected may provide a measure of disease severity.

Although it is known that plant diseases reduce crop yields compared to yields that could be expected in the absence of disease, it is usually difficult to obtain accurate quantitative estimates of yield reductions caused by specific diseases. Many diseases occur on senescing tissue which may not have been contributing much to yield. Plants are capable of compensating for loss of a certain amount of leaf area, especially in crowded crop populations. The only diseases where the effect on yield is relatively easy to measure are those that kill entire trees in orchards or plantations (e.g. phytophthora root or collar rot of citrus or apple), and those that destroy the actual harvested product, either just before harvest (e.g. the smuts, which destroy cereal grain, and fruit rots such as cocoa pod rot caused by Phytophthora palmivora) or after harvest (all postharvest rots of fruits and vegetables).

Reduced yields caused by pests and diseases are commonly referred to as 'crop losses', although some pathologists prefer to think of disease as a 'yield
limiting' factor or a 'constraint on yield' rather than as a cause of 'crop loss', contending that you cannot lose what you never had in the first place. Viewed in this way, the impact of disease is expressed more directly as the increase in yield when it is controlled rather than as the prevention of a 'crop loss'. However, 'crop loss' is a useful shorthand way of expressing the impact of a disease and it is certainly one that farmers understand when they compare their yields in one year in the presence of disease with their yields in previous years in the absence of disease.

Disease and crop loss assessments are necessary before the economic impact of a disease and the benefit of particular control strategies can be determined. Ideally, this knowledge is required before much effort is expended on studying a particular disease. In reality, most diseases have been studied because people sensed that they were causing yield losses and therefore required study and the development of control measures. The economic advantage of any control method has to be determined. It is no use implementing a control measure that costs the farmer more than it returns in increased yield. Often in the past the economic value of control measures was based on vague qualitative assessments, but for a more accurate measurement of economic advantage, disease assessments have to be quantitative. The growth of the crop, its yield potential, the development of the disease and its impact on yield all have to be measured as a basis for predicting the impact on yield of particular levels of disease. This information can be combined with predictions of likely disease levels in deciding whether implementation of control measures is warranted.

The economic advantage of any control strategy can be estimated by applying the following formula:

\[
\text{Economic advantage of disease control (S)} = \frac{\text{Expected return if disease is controlled (S)}}{\text{Expected return if the disease is left uncontrolled (S)}} - \left(\frac{\text{Cost of control treatment (S)}}{\text{Cost of control treatment (S)}}\right)
\]

The economic advantage of control is clearly affected by the difference between the economic return if the disease is controlled and the return if it is not, which is determined by the 'crop loss' caused by the disease, the measurement of which is the main concern of this chapter. However, this is also determined by the economic value of the crop. A crop like coffee, cocoa, macadamia nuts or a vegetable with a very high value per unit weight of harvested product, will be able to sustain a greater expenditure on disease control than a relatively low value production system such as a pasture. The yield potential of a crop and hence the economic return if disease is controlled also determines the amount of expenditure on disease control that can be sustained. Australian wheat farmers producing an average of about 2 tonnes per hectare under conditions of water and nutrient deficit can spend less to control stripe rust (\textit{Puccinia striiformis}) than European farmers who produce an average of about 8 tonnes per hectare under more favourable environmental conditions.

It is obvious therefore, that decisions based on disease assessment data are critical in the economy of any farm. Furthermore, from the national standpoint, disease assessment information is fundamental for the prediction of crop yields as a basis for the smooth running of markets and financial planning. It also enables problem areas to be recognised and permits priorities for future research and development to be placed on a sound economic basis.

Much of the published work on disease assessment and crop losses has been qualitative rather than quantitative. This has led to disease incidence being described in vague terms such as 'severe', 'debilitating', 'mild' or 'of little
20. Assessment of disease and effects on yield

20.1 Consequence. Qualitative assessment of disease provides inaccurate and often misleading data. It does not enable comparisons to be made between the results of different workers or between results obtained from different seasons or locations.

Quantitative assessments of disease are based largely on comparisons between the yields obtained from diseased or damaged crops and those obtained from healthy or undamaged crops. Comparisons can be made between diseased and disease-free plants in the same crop or between diseased and disease-free plants or crops grown in different locations, provided that the locations have similar environmental conditions.

One major difficulty associated with disease assessment is the rarity in nature of a 'one cause—one disease' situation. Under field conditions, plant growth and yield are influenced by many factors including nutrients, rainfall, insects, weeds and pathogens. It is difficult, therefore, to determine the relative importance of different factors in limiting yield. There are often complex interactions between the constraints on yield. For example, the impact of a root rotting pathogen will be much greater in a drought year than a wet year, or in an infertile soil than a fertile one. The impact of foliar pathogens (e.g. rusts and powdery mildews) that disrupt the plant cuticle and so affect the water relations of a plant, will be greater in a dry than in a wet year.

The assessment of plant diseases and their effects on yield normally involves five distinct processes: (i) developing a descriptive growth stage key for the particular crop species in question, (ii) developing methods to assess the incidence and severity of disease, (iii) developing statistically sound methods of sampling crop populations for assessment of the amount of disease, (iv) estimating the negative impact of particular levels of the disease on crop yield and quality and (v) evaluating the economic benefit from various methods available for reducing the amount of disease.

20.2 Assessment of crop growth and development

While plant pathology tends to concentrate on the diseased plant, it should be realised that to understand the impact of a disease fully it is necessary to understand the growth, development and physiology of the healthy plant.

One of the first steps in quantitative disease assessment is to obtain or develop a key that describes the growth and development of disease-free plants during the growing season. In annual plants, the keys describe development from the time of sowing or planting until harvest. In perennial species such as tree crops, variations in growth patterns between seasons are described, often beginning with bud burst in spring. In tropical perennial crops the starting point is more difficult to determine since growth often occurs throughout the year. It is therefore often necessary to nominate a more arbitrary starting point (e.g. a particular growth flush at the beginning of the wet season).

Detailed drawings or photographs are needed to show such characteristics as the structure of the canopy at various stages of crop growth, the formation of new leaves and the senescence of older leaves, the development of reproductive structures and different stages in the formation of grain or other harvested products. Detailed information on the development of healthy plants is needed before the effects of disease on crop growth and development can be assessed. For example, it is important to distinguish between normal senescence of leaves and damage caused by parasites. Some parasitic fungi develop mainly on senescing leaves and so their impact on yield is probably small. They may just be speeding up the process of decay of senescent leaves.
Descriptive and pictorial growth stage keys have been developed for a number of crops including wheat, oats, barley and rye (Fig. 20.1), maize, rice, tobacco, cotton, legumes, broad beans (*Vicia faba*), black currants and *Narcissus* and *Chrysanthemum* flowers. With some species, such as wheat, several different growth stage keys are in use. It is helpful if standardised growth stage keys are used around the world, enabling ready comparison of results from different countries. However, with many crops that have been little studied, it may be necessary for investigators to construct their own keys.

**Growth Stage**

1. One shoot (number of leaves can be added).
2. Beginning of tillering.
3. Tillers formed, leaves often twisted spirally. In some varieties of winter wheats, plants may be 'creeping' or prostrate.
4. Beginning of the erection of the pseudo-stem, leaf sheaths beginning to lengthen.
5. Pseudo-stem (formed by sheaths of leaves) strongly erected.
6. First node of stem visible at base of shoot.
7. Second node of stem formed, next-to-last leaf just visible.
8. Last leaf visible, but still rolled up, spike beginning to swell.
9. Ligule of last leaf just visible.
10. Sheath of last leaf completely grown out, spike swollen but not yet visible.
10.1 First spikes just visible (awn just showing in barley, spike escaping through split of sheath in wheat or oats).
10.2 Quarter of heading process completed.
10.4 Three-quarters of heading process completed.
10.5 All spikes out of sheath.
10.5.1 Beginning of flowering (wheat).
10.5.2 Flowering complete to top of spike.
10.5.3 Flowering over at base of spike.
10.5.4 Flowering over, kernel watery ripe.
11.1 Milky ripe.
11.2 Mealy ripe, contents of kernel soft but dry.
11.3 Kernel hard (difficult to divide by thumb-nail).
11.4 Ripe for cutting, straw dead.

**Figure 20.1** The Feekes scale for describing growth stages of cereals. (From Large, 1954. Crown copyright is reproduced with the permission of the Controller of Her Majesty’s Stationary Office.)
20.3 Methods for assessing disease incidence and severity

Disease assessment methods should (i) provide objective measurements so that results obtained by different workers, from different locations and from different seasons are comparable, (ii) be simple and quick to use, (iii) be related to an identifiable growth stage of the crop and (iv) provide an adequate sample of the entire area of crop to which the assessment refers.

Thus, disease assessment of a crop encompasses two main aspects—assessment of disease in samples from the crop and adequate sampling from the whole crop.

**Measurement of disease incidence and severity**

Whether or not disease incidence or severity or both should be measured will depend on the disease, the particular epidemiological circumstances and the reason for undertaking the disease assessment. With systemic diseases (e.g. many virus diseases) or root diseases (e.g. phytophthora root rots) that infect and kill whole plants or when the disease causes similar amounts of damage on plants within a crop, the disease incidence, expressed as the percentage of plants showing symptoms or damage, may suffice. At low levels of disease there is often a linear relationship between incidence and severity, and so it is sufficient to measure incidence. However, at high levels of disease there is often not a simple, consistent relationship between incidence and severity. Many diseases cause different levels of damage on different plants within a crop. In such situations it is necessary to assess disease severity. The impact of a disease on yield is often determined by the extent of disease on the nearly mature plant (e.g. on the flag leaf and head of cereals). At this stage, disease severity is usually a better predictor of crop loss than disease incidence. Thus, for most crop loss assessments, severity is required.

Measurement of disease severity is more difficult and error-prone than measurement of disease incidence. Disease incidence is based on counting infected and uninfected units of the crop (whole plants for systemic diseases, inflorescences for smuts, leaves for leaf spots and rusts etc.). From these counts the proportion of units infected is calculated. An example was given in Chapter 19 of the measurement of the incidence of blister blight of tea as a basis for forecasting the amount of disease likely to occur 2–3 weeks later. The main problem in determining disease incidence is establishing the extent of sampling that is required to adequately represent the crop.

Determining disease severity often requires estimating the proportion of the total photosynthetic area of the crop that is diseased which is often called the ‘proportion of leaf area affected’. This measurement is much less precise and less controllable than measurements based on counting individual plants. Disease severity assessment relies on visual judgments which tend to be deceptive and to vary greatly from person to person. The human eye tends to detect grades of disease severity in logarithmic steps (5%, 10%, 20%, 40%, 80%) rather than in the uniform, arithmetic steps (5%, 10%, 15%, 20%, 25% etc.) by which we like to express quantities. Accordingly, various modifications of percentage scales have been proposed to take into account this fact and allow more accurate measurement of disease severity. Moreover, when less than 50% of the tissue is diseased or damaged, the eye tends to focus on or estimate the proportion of diseased area, but when more than 50% of tissue is damaged the eye tends to focus on or estimate the proportion of healthy tissue.

The most common method of estimating disease severity is the use of a set of diagrams (**disease assessment keys**) of a crop (commonly leaves, but it could
involves inflorescences, fruits or whole plants) showing different disease severities as blackened areas. Severity scales are adjusted to take into account the above concepts of visual perception. Samples of the crop are then compared with these diagrams to allow an assessment of severity. A disease index for a crop can be obtained by summing the individual disease assessments and then dividing this by the number of plants assessed.

For common diseases it is helpful to use published keys to standardise measurements around the world. However, in some cases such as for new diseases or in particular circumstances it may be necessary to develop one's own key. To produce a disease assessment key, the development of disease over the whole disease cycle and at different stages of plant growth must be studied. Drawings and measurements of the diseased plant at various stages of development are required and the various parts of the plant that are damaged must be analysed. This information is used to develop prototype standard diagrams which may involve photographing or tracing symptoms onto paper and accurately measuring the proportion of the tissue diseased. Alternatively, the area of leaves and the area of disease can be measured using an electronic ‘leaf area meter’ or a video camera and image analysing equipment connected to a computer. Eventually, the key is simplified to enable rapid and accurate measurement of the disease under field conditions. For crop loss assessments, the key has to be set so that it measures the disease at the stages of crop development that are critical for yield. The scale then has to be tested in the field in an objective way. For example, a researcher may assess a range of diseased samples with the key and then compare the results with objective measurements in the laboratory of the same samples. Some examples of descriptive and pictorial disease assessment keys are shown in Tables 20.1 and 20.2 and in Figure 20.2.

Table 20.1 Key for the assessment of leaf mould of tomato caused by *Fulvia fulva*. (From Beaumont, 1954.)

<table>
<thead>
<tr>
<th>% Severity</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>Lesions found with difficulty, and on less than one plant in fifty.</td>
</tr>
<tr>
<td>1</td>
<td>Lesions on most plants, but only on a few leaves.</td>
</tr>
<tr>
<td>5</td>
<td>Lesions on every plant, and on most leaves except the young ones, but only about two to ten spots per leaf.</td>
</tr>
<tr>
<td>10</td>
<td>All except the youngest leaves affected, with ten to fifty spots per leaf.</td>
</tr>
<tr>
<td>25</td>
<td>All except the youngest leaves affected, but with about three-quarters of the leaf area green, although lowest leaves may be severely attacked.</td>
</tr>
<tr>
<td>50</td>
<td>All leaves affected. Most of the middle leaves showing only half their area green.</td>
</tr>
<tr>
<td>75</td>
<td>All leaves affected. Most of the middle leaves show only one-quarter of the leaf green, giving a grey appearance to the crop as a whole.</td>
</tr>
<tr>
<td>90</td>
<td>Very little green visible on middle and lower leaves, but youngest leaves show green.</td>
</tr>
<tr>
<td>100</td>
<td>All leaves completely covered with the lesions.</td>
</tr>
</tbody>
</table>

The development of a key and its field testing is actually a way of training a researcher’s eye to recognise the various disease severity categories. Eventually a highly trained observer will conduct the whole assessment by eye. However, even highly trained observers need to standardise or calibrate their visual assessments by regular comparison with objective measurements. For example, people differ greatly in their ability to accurately assess percent leaf area diseased. Some people tend to overestimate, others to underestimate, and others
to overestimate at low disease levels and underestimate at high levels. Regular objective testing allows statistical confidence intervals to be established for a particular observer under particular conditions. Programs have been developed for computer-assisted training of observers in disease severity assessment. The computer program develops diagrams of a diseased leaf with different severity levels. The observer estimates the severities, the program then compares their performance with the known severity and gives them feedback on the extent of their errors, allowing further training of their visual perception.

Table 20.2 Key for the assessment of late blight of potato caused by Phytophthora infestans.
(After British Mycological Society, 1948.)

<table>
<thead>
<tr>
<th>% Severity</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Disease not seen in field.</td>
</tr>
<tr>
<td>0.1</td>
<td>Only a few plants affected here and there. Up to one or two spots in 10.8 m radius.</td>
</tr>
<tr>
<td>1</td>
<td>Up to ten spots per plant or general light spotting.</td>
</tr>
<tr>
<td>5</td>
<td>About fifty spots per plant, or up to one leaflet in ten attacked.</td>
</tr>
<tr>
<td>25</td>
<td>Nearly every plant with lesions; plants still retaining normal form; fields may smell of blight but look green although every plant affected.</td>
</tr>
<tr>
<td>50</td>
<td>Every plant affected and about half of the leaf area destroyed by blight; field looks green flecked with brown.</td>
</tr>
<tr>
<td>75</td>
<td>About three-quarters of the leaf area destroyed by blight; field looks neither predominantly brown or green. In some varieties the youngest leaves escape infection so that the green is more conspicuous.</td>
</tr>
<tr>
<td>95</td>
<td>Only a few leaves left green, but stems green.</td>
</tr>
<tr>
<td>100</td>
<td>All leaves dead, stems dead or dying.</td>
</tr>
</tbody>
</table>

Because different assessors vary in their assessments, if two people are required to carry out a disease assessment each observer should do half the number of replicates so that any error due to the different observers appears in the error mean square of the analysis of variance.

Assessment of severity of leaf disease on eucalypt saplings has involved use of diagrams to represent the whole tree. The diagrams show the extent of disease on middle and upper branches and the extent of abnormal leaf loss on lower branches. They have been used to measure the degree of resistance of various provenances of eucalypts, but assessments of disease on whole plants are more prone to error than assessments on samples of single branches or single leaves. For example, assessments of whole trees can be greatly affected by the quality of the light and the degree of shading of one tree by another. Bright sunlight can obscure the extent of disease and result in a different assessment from one done on an overcast day.

Root diseases are often assessed using an arbitrary scale such as the 0 to 5 scale of Greenhalgh and Lucas (1984) for root rot of subterranean clover, where:

0 = healthy roots (no visible lesions on roots)
1 = slight lateral root rot (less than 10% of lateral root tips necrotic)
2 = moderately severe lateral root rot (10–50% of lateral root tips necrotic) or slight tap root rot (tip of tap root rotted) or both
3 = severe lateral root rot (greater than 50% of lateral root tips necrotic) or moderately severe tap root rot (5–30% of tap root rotten from tip) or both
4 = severe tap root rot (greater than 30% of tap root necrotic with healthy laterals above lesion or lesion girdling tap root immediately below hypocotyl)
5 = tap and lateral roots completely rotted or plant dead.
Infected root systems can be surface sterilised and plated onto selective media, which allow the pathogen to grow out of the region of the root that is infected. The proportion of the root system infected can then be measured.

**Figure 20.2** Disease assessment keys. (A) Common scab of potatoes caused by *Streptomyces scabies*. (From James 1971.) (B) Mycosphaerella leaf diseases of eucalypts. (From Carnegie et al. 1994.) (C) Phytophthora blight (*P. colocasiae*) of taro (*Colocasia esculenta*). (From Gollifer and Brown, 1974.)
Some workers have used electronic root length measuring devices to determine the extent of root loss in infected, compared with uninfected, root systems.

Disease incidence can be also assessed using remote sensing techniques. For example, the incidence of rusts such as Puccinia graminis in cereal crops has been measured using spore traps to determine the quantity of spores arising from the diseased crop. This method assumes that spore production is directly related to the amount of disease in the crop. This is not always so (see the example of tea blister blight in Chapter 19). It has the advantage that the disease assessment is made without actually walking into the crop, a practice that may alter the rate of spread of disease due to the disturbance resulting from intrusion into the crop. Other remote sensing techniques include the use of electronic scanners and other instruments to produce quantitative estimates of disease incidence from data on infrared (IR) aerial photographs. Such IR photographs can be taken from either aircraft or satellites. Methods have even been developed to take disease assessment photographs from radio-controlled, model aircraft.

Video cameras and image analysis can be used to objectively measure disease severity in the field, but to date these methods are too cumbersome and time consuming to replace the trained human eye in all except experimental assessments.

Finer measurements of disease severity not only enable more accurate assessment of the impact of disease on yield but also enable better assessment of the effect of quantitative resistance and other control measures. It is likely that in the past much useful resistance was discarded from breeding programs because the small amount of resistance it contributed was not assessable using broad-brush assessment methods. It is now appreciated that even small amounts of resistance may be important in disease control in combination with other control measures and that even small amounts of partial resistance may be useful in combination with other sources of resistance in breeding programs.

**Sampling for disease incidence and severity assessments**

Most of the disease assessment methods referred to above are applied to samples taken from the whole crop or plantation area. Therefore, a major limitation in the overall assessment of disease is the sampling method. The disease assessment will only be accurate if the sampling method enables accurate extrapolation to the entire crop.

Samples of crop units (plants, leaves, inflorescences etc.) can be taken at random from a field (e.g. by following a set of random number coordinates, or a randomly chosen number of paces across the field) or in a predetermined way (e.g. by walking across a diagonal or in a 'W' or diamond pattern across the field and taking a sample every 10 paces). Random sampling is preferred by biometricians. There are programs available for portable computers that indicate the random number of paces for sampling during a 'walk pattern' through a field.

Alternatively, standard quadrats can be placed at random in a field and all plants within each quadrat assessed. In experimental plots often a part of each plot is assessed for disease. Because of the influence of 'edge effects', taking a few samples from the edges of fields is never sufficient to accurately reflect the disease situation throughout the field. This is a problem in sampling leaf disease in eucalypt forests. Often the best view of the disease in the foliage is from roadsides where the edge of the forest is exposed. However, this may not reflect the occurrence of disease in the bulk of the forest.
The intensity of sampling should be determined for each disease situation. It will depend on the uniformity of disease in a plant population. A disease spread uniformly throughout a crop will require fewer samples for accurate assessment than one with a patchy distribution through the crop. It is possible when developing the methodology for studying a particular disease, to sample a certain number of times at each of progressively increasing levels of sampling intensity. The standard error of the mean disease incidence or severity at each sampling intensity can then be plotted against the sampling intensity. The optimum sampling intensity is determined as the one at which the standard error first falls to a low level which is maintained even at much higher sampling intensities (Figure 20.3). It is a waste of time taking a larger number of samples if they do not greatly reduce the standard error of the assessments.

![Standard Error vs Sampling Intensity](image)

**Figure 20.3** Plot of standard error of mean disease assessment measurements against sampling intensity, showing the point at which the standard error declines to a relatively stable low level (approximately the optimum sampling intensity).

### 20.4 Assessment of crop losses

Having determined the amount of disease in relation to the growth pattern of a crop, the next step is to determine the effect of different levels of disease on yield of the crop. The two main approaches used to relate disease intensity to crop losses are the experimental and the statistical.

**The experimental approach**

The experimental approach to crop loss assessment usually involves setting up experiments in which the level of disease in a crop is controlled using different levels of inoculation or treatments with biocides (fungicides, nematicides, bactericides). Often, an intensive spraying schedule is used to hold disease to a level close to zero, which allows the potential yield of the crop in the absence of disease to be determined. A reduced spray treatment may allow development of a moderate disease severity, while withholding of treatment may allow development of a severe epidemic. This allows a comparison of epidemic progress and yields in the plots. From this a relationship between disease parameters and yield can be determined, allowing prediction of crop loss based on certain disease intensities at certain periods of crop growth. The value of this
method depends on the assumption that the biocide treatment itself has no direct effect on yield. In some cases this assumption is not valid. For example, sprays of copper-based fungicides used to control coffee rust often have a direct 'tonic' effect on yield of coffee, quite apart from any indirect effect they may have through control of rust. In these studies it is important to determine the effect of a biocide on yield in the absence of disease.

A comparison between epidemic progress and yields can also be obtained from experiments using susceptible and resistant cultivars of the same plant species. The value of this method is dependent upon the susceptible and resistant cultivars having similar yield potentials in the absence of disease. Again, this has to be determined under disease-free conditions. Near isogenic lines of a crop, which are genetically similar except for the presence of a specific gene for resistance, are sometimes used to investigate the effects of disease on growth and yield.

Before undertaking experiments to determine the effects of disease on crop yields, careful consideration should be given to experimental design, including the shape and size of plots, interplot interference, paired-plot versus multiple-plot treatments and so on. The harvesting methods used in experiments tend to be more efficient than those used in commercial farming practice. Consequently, allowances should be made for this when applying data to commercial situations. Any method used in disease assessment should provide data that can be analysed statistically, particularly by regression analysis. A common approach is to determine regression relationships between certain measurements of disease (plotted on the X axis) and yield (plotted on the Y axis). From these studies, mathematical models can be developed that express relationships between disease intensity and crop losses. The aim with these models is to reduce the usually complex relationship between disease intensity and yield to a simple relationship that can be applied in farmers’ fields to enable prediction of crop losses. Crop loss assessments are often combined with the prediction of disease levels in determining whether control measures are required. Three main types of disease assessment have been used to develop crop loss models—disease at a critical point in crop development, disease at multiple points during crop development and disease throughout crop development as measured by the area under the disease progress curve.

Critical-point models

Critical point or single point models are based on a disease assessment that is made at a given time in the plant’s life (the critical point) and then related to yield loss. Relationships between the amount of disease and percentage loss in yield are usually expressed in the form of linear regression equations where the independent variable is disease intensity (X) at the particular stage of crop development and the percentage loss in yield (Y) is the dependent variable. For example, the mean percentage reduction of grain yield attributable to powdery mildew in spring barley and oats in the United Kingdom can be expressed as

\[ Y = 2.5 \sqrt{X} \]

where X is the percentage of mildew at the 10.5 stage of plant growth (see Fig. 20.1). Thus, if 25% of the plant is covered with mildew at the 10.5 stage of plant growth, one might expect a yield reduction of 12.5%. Similarly, loss in yield due to rice blast in Japan can be estimated by the equation

\[ Y = 0.57X \]

where X is the percentage of blasted necks (culm region immediately below the inflorescence) at 30 days after heading. In these examples, the disease severity was measured at a specific stage of plant growth (the critical point).
Other critical point approaches use observations of disease-free periods or disease thresholds to predict crop losses. In the United Kingdom, 75% late blight severity is used as a predictor of crop loss in potato. If it occurs in late July (mid-summer), 50% loss is predicted, but if it does not occur until mid-September (early autumn) only a 4% loss is predicted.

A major criticism of critical point models is that they do not take into account the possibility that infection rates ($r$) may vary throughout an epidemic. They ignore the shape of the disease progress curve. The model cannot distinguish between a short, severe epidemic and a long, less severe epidemic if both happen to have the same amount of disease at the critical point (Fig. 20.4). However, they may be very useful when disease progress is relatively uniform or when the amount of disease at a certain stage of crop development has a dominant effect on yield.

![Figure 20.4](image_url) Two very different disease progress curves that show similar amounts of disease at a critical point. (From Parbery and Brown. 1980.)

**Multiple-point models**

To develop multiple-point models, disease assessments are made at regular intervals during development of the epidemic. An empirical equation obtained by multiple regression analysis can be used to estimate yield losses for disease progress curves showing different characteristics. The general form of the regression equation is $Y = a + b_1X_1 + b_2X_2 + ... + b_nX_n$ where $Y$ is the loss in yield and $X_n$ = the amount of disease measured at the $n^{th}$ assessment time. The constants $b$ can be determined from the crop loss experiments described above.

Multiple-point models are especially useful in yield loss analyses where infection rates are variable, where the shape of the epidemic progress curve varies and for epidemics of different lengths. Because they take into account variations in epidemic progress, they are regarded as allowing more accurate yield predictions. In practice the concepts of the critical point and multiple point models are often combined because the multiple point observations are often made at especially chosen critical stages in the development of the epidemic or the crop (i.e. stages at which the observations have greater predictive value for yield).
Area under disease progress curves

The relationship between disease and yield loss can be determined by studying the area under the disease progress curve (AUDPC). This is based on similar logic to the multiple point model except that it involves integration of the entire disease progress curve. The model assumes that yield loss is proportional to the amount of disease and that yield reduction is proportional to the duration of the disease. Compared with the critical point model it has the advantage that it can distinguish between two epidemics with different areas under the curve but which have the same percentage severity at a critical time (Fig. 20.4). The main disadvantage of the model is that it does not differentiate severity of disease relative to time. James (1974) pointed out that when the model was applied to potato blight epidemics, it could not distinguish between epidemics which commenced at different stages in the plant’s growth but which showed similar areas under the disease progress curve (Fig. 20.5). He found that early light infections caused greater yield reductions than late, severe infections even though the areas under the disease progress curve were the same. This problem could readily be overcome by inclusion in the model of a factor which relates AUDPC to particular stages of crop development.

![Graph](image)

**Figure 20.5** Two very different disease progress curves that show similar areas under the disease progress curve. (From Parbery and Brown. 1980.)

The statistical approach

This approach to disease assessment involves statistical analysis of yields under different levels of disease that occur naturally in the field. The methods used include: (i) comparisons of yields obtained from crops in seasons with different disease intensities, (ii) comparisons of expected (based on, for example, experience under disease free conditions on experimental stations) and actual yields, (iii) comparisons of the yields of a particular crop with the average yield for the region and (iv) comparisons of epidemic progress and yield parameters between crops or portions of a crop showing different levels of infection or damage. These comparisons can be very useful because they are based on the real cropping situation in the field rather than on experimental plots, which often give artificially high yields. However, account has to be taken of the fact that in the field many other factors besides disease will affect the yield. Using statistical analysis of natural disease epidemics, critical point, multiple point and AUDPC models relating crop loss to epidemic development can also be determined.
20.5 Plant disease surveys

Another statistical approach to assessment of crop loss involves the use of questionnaires to assess disease (and pest) incidence or severity. Results of farmers' assessments of disease can be related to the yields eventually obtained.

Appraisals of disease and yield-loss are often of limited value because of the difficulty of obtaining information concerning the prevalence and severity of diseases over large areas. For this reason there is a special need for an increased use of plant disease surveys. The information obtained from plant disease surveys enables the relative importance of different diseases to be determined, which in turn enables rational allocation of resources for research as well as control and eradication programs.

Disease surveys are also necessary to establish: (i) the geographic distribution of pests, pathogens and their various pathotypes, (ii) the rate of spread of newly introduced pests and pathogens, (iii) the presence of other hosts of pathogens and pests and (iv) 'breakdowns' in disease resistance used in crop plants.

20.6 Further reading


