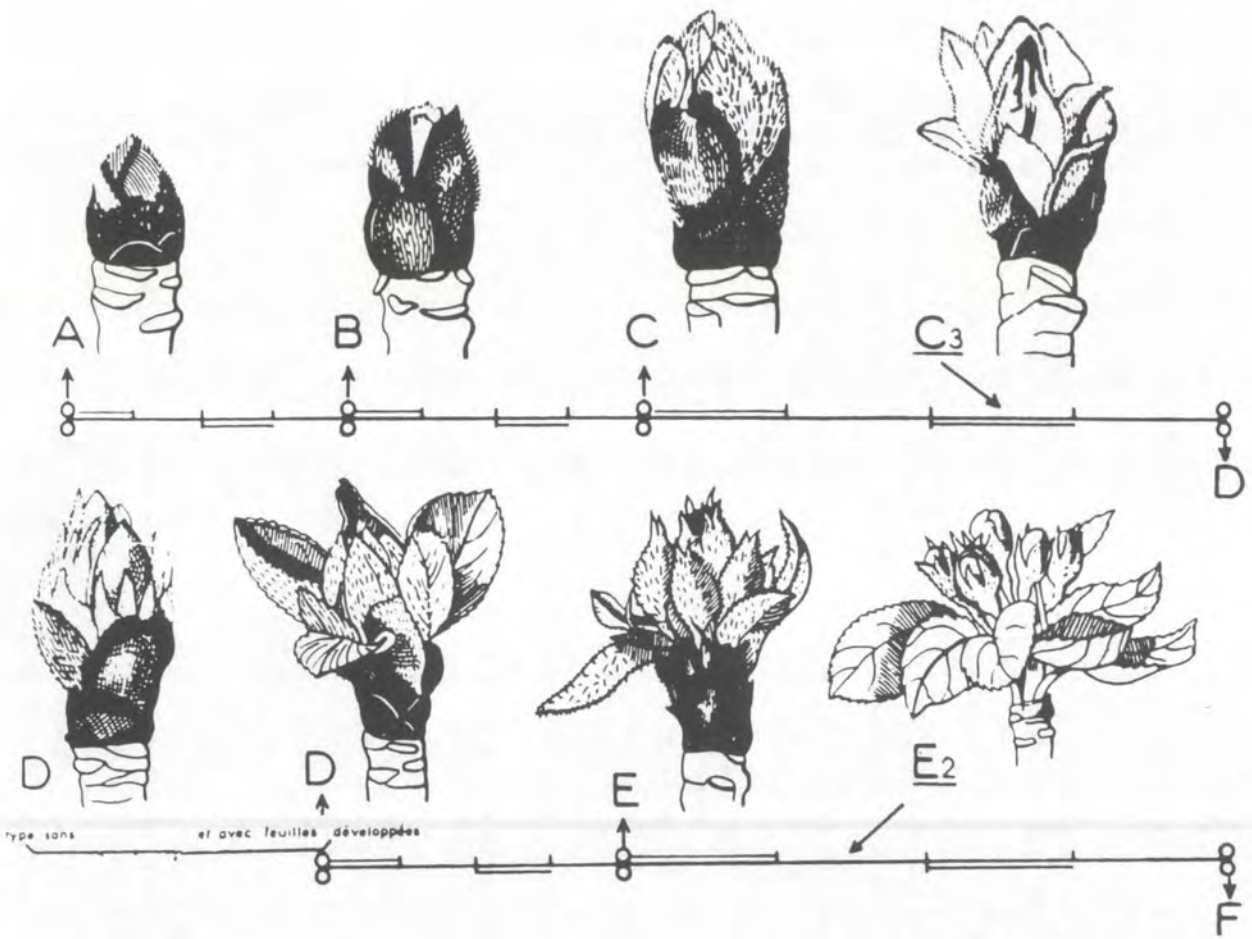

Fig. 5.2: Example of a growth stage key of perennial crops, here: apple (Anonymous, 1952)

Within real monitoring purposes for decision making, information on the leaf area index, however, has a rather limited value, it is of greater importance in applied research analyzing epidemics of plant diseases and population dynamics.

Accurate measurements of **leaf area index** are laborious though not necessarily very costly. The techniques used for leaf/root area measurement are principally:

(1) **electronic methods**, using special electronic equipment of which the leaf area meter is still the most common and simple one,

(2) **related-measures methods**, by which the dry weight of leaves is converted into leaf area approximations using a regression model,

(3) **visual estimates**, using grid paper, set of leaf drawings of different sizes, photocopies of leaves, etc. prepared as an aid for visual assessment of leaf areas.

The practical on assessment techniques of host plant population (practical instruction # 4.2) will treat the topic of leaf area measurement more in detail.

5.3 Exercises

1. In a given rice field rice plants were transplanted at 0.25 m in the row and 0.40 m between the rows with 1 plant/ planting hole. On average, the rice plants produced 15 tillers each. At the time of measurement, each tiller had 14 leaves with an average size of 31,5 cm^2 per leaf.

Questions:

a) What is the crop density per hectare (number of tillers)?
b) What is the leaf area per hectare?
c) What is the leaf area index of this particular rice crop?

2. In an area of 100 ha the proportion covered by beans is 0.2. The bean crops have a LAI of 5 and a rust severity of x = 0.4.

a) Calculate the diseased leaf area in m^2.
b) What is the DAI and its dimension?
(DAI = diseased area index)

6. EVALUATION OF PEST INFESTATION

6.1 Importance and use of pest assessment

The monitoring of pest infestation in a given field, area, region, etc. is intended to give information on whether or not a given pest (or various pests) is present and how much of the crop is affected. This is mostly done in one of the two ways: by **counting** the numbers of pests present in the crop (easy to do with insects or mites), or by counting the numbers of plants/plant parts affected, or by visual estimation of the proportion of plants/plant parts infested. Such counts or assessments have manifold uses, in regional surveys and individual fields, and in experimentation and advisory work, and the methods which are employed may vary according to the degree of accuracy required and the time available.
Pest and injury assessment is essential for several aspects of pest management:

(a) It provides information on the presence/absence of a pest and its density.
(b) It is used to study and understand the biology of pests and their progress in time and space (distribution, migration).
(c) It is used for analysis of the factors that affect pest development.
(d) It provides the basis for yield loss predictions: Pest surveys, pest forecasts and studies of the effects of pesticides rely heavily on methods of assessment.
(e) In particular, pest management decisions based on economic benefit demand a quantitative measure of pest attack to relate to the increase in yield resulting from pest management.

If such decisions are based on an economic action threshold (see chapt. 3), a measure of the pest density or amount of injury is an essential part of the decision making system.

The principal **methods** for monitoring pest infestation can be classified into *direct counts* of pests (e. g. population densities), *indirect counts of effects* caused by pests, and *ratings* of infestation or injury. When evaluating the effect of a pest it is important to know which plant part is injured (see box 6.3). This can be: (a) the plant part that has to be harvested, e.g. fruits (*direct injury*) or (b) a plant part necessary for the growth and development of the product that has to be harvested, e.g. flag leaf of cereals (*indirect injury*), (see also below).

When evaluating the injury, damage or loss caused by a pest it is important to dispose of reliable assessment techniques:

Counting pests or affected plants:

Wherever counting is feasible, it is preferable to appraising populations of pests or of affected plants, since appraisal has an element of subjective decision making. Counting serves mainly for the determination of pest populations on the plant parts above the ground (counting of soil-borne nematodes or fungal bodies, such as sclerotia, require special equipment and expertise). Counts are also used to indicate the percentage of plants showing symptoms on the whole or most of the plant, such as virus infection, wireworms, fungal and bacterial wilting agents.

Visual assessment of symptoms:

Several terms have been used to define aspects of pest measurement: **prevalence, incidence, severity** and **intensity**.

Prevalence (=the proportion of plant units in which at least some proportion of the pest may be found) is mostly used in survey work. Pest intensity is used as a general term for the amount of pest present, often based on **incidence** and/or **severity**. Visual assessment of symptoms has to take into account both the *incidence* and the *severity* (see box 6.1) of whatever ails the crop.

Incidence is an appropriate measure for assessing diseases and those insect pests of which the symptoms are easier to determine than their numbers: e.g. plant diseases causing wilts, smuts, damping offs, etc., or insect pests causing leaf curling, bud mites, some stem borers, etc. **Incidence** is often the easiest and quickest measure of pest infestation, therefore it is preferably used in monitoring for decision making.

Severity assessment is convenient where (a) symptoms are clearly defined (e.g. leaf spots, rusts, mildews), and (b) a single pest is dominant. It is much more difficult to use where symptoms are not well defined, where several causes (parasitic or not) are potentially involved, and where tissue dries up or organs shed.

Severity is a more important and useful measure of pest infestation, especially plant diseases, for investigation in many pathosystems that relate to disease management, population dynamics and crop loss assessment. Estimating grades of severity invariably involves a certain amount of bias: It has been observed that estimates of *severity* of a pest within and between persons are poorly reproducible. It is also a known fact that estimators tend to overestimate severities. If there is a simple correlation between *incidence* and *severity* of a pest it would be easy to determine the severity if one knows the incidence (see box 6.1 and practical instructions no. 4). Probably the relation between incidence and severity depends on parameters such as variety, cropping system, place and time.

Pest assessment methods should be standardized so that they can be studied and tested, and different results compared. The techniques used for the evaluation of pest infestation should be quick, simple and cheap, and clearly described in standard protocols or accompanying explanatory manuals, with details of the *pest life-cycle* and *crop cycle* at which they are taken. A **key** to identify the pest and crop growth stage is important. Also, an estimate of the accuracy, or nearness to the true value and precision in relation to the mean is needed.

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BOX 6.1

Severity-Incidence Relationship
(Zadoks, 1985)

Phytopathologists often assess disease as severity, or the proportion of leaf area visibly infected by disease. Entomologists and phytopathologists may differ in their definition of severity. For phytopathologists severity refers to the mean intensity of disease all over plants, both healthy and diseased, in a plot or field. Entomologists may restrict their meaning to the degree of attack on infested plants only, without taking healthy ones into consideration.

Severity estimates can be reliable when made by trained persons who are supported by pictorialized keys and who regularly compare results. The reproducibility of severity estimates between observers is generally poor, at least with diseases. Severity estimates as a means to establish damage thresholds for foliar diseases cannot be recommended. A farmer concerned about his crop readily overestimates severity, as I have seen but too often. In practice, there is little objectivity in severity estimates.

Counting is more precise than estimation, and recent work relies on incidence counts rather than on severity estimates. Incidence is the proportion of plant units (plants, stems, leaves) visibly affected by the harmful agent. Incidence is determined by following a clear and rigid sampling and counting protocol. The results have been reproducible among researchers, although instruction and training is needed here, too. Many schemes warning against insect pests depend on sampling and counting procedures; only few disease warning systems do so. Among the latter is Epipre.

At low disease or pest levels, good correlations between severity and incidence have been found. At high disease levels, the relationship between incidence and severity becomes indeterminate. Much earlier work on incidence-severity relationships was ill spent because it was aimed at high severities, when it was too late to effect change, instead of low severities, when disease warnings are timely. For aphids, severity is determined by the number of insects per plant or per stem and incidence by the number or proportions of stems carrying at least one aphid. The remarkably good severity-incidence relationship holds when compared internationally. Incidence counts using a good protocol may also offer a solution to the problem, too often underestimated, that lesions of the same size but on different plant parts have different effects on damage.

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Up to date a large number of methods to measure pest infestation are known from the literature, the principle ones are described in chapters 6.2 and 6.3. Almost each crop/pest-system requires its individual assessment methods.
Especially those techniques used for monitoring have to be simple and time-saving. They therefore have to concentrate (a) on the most important pests and (b) on the tissues or plant parts most susceptible towards attacks, e.g. buds, young foliage, root collars, etc. *Action thresholds* (see chap. 3) must then refer to pest populations or tissue affected in these plant parts, especially when these are to be marketed, such as fruits, or have a particularly marked influence on yield such as the flag leaf of cereals.

6.2 Monitoring plant pathogens and diseases

The assessment of the amount of disease and pathogens present is fundamental to crop loss studies and to many types of disease prediction and management systems. Disease assessment is also necessary for epidemiological studies, plant breeding and studies on chemical efficacy, leading to a diversification of methods to suit particular requirements:

Disease assessment may be quantitative, qualitative, or a combination of both. The **quantity** of disease is also called *disease intensity*. Within disease intensity, we can distinguish *disease incidence* and *disease severity*. Additionally, such characteristics as *number of sporulating lesions* and *concentration of colony-forming units* in tissues can reflect disease intensity. **Qualitative** measures of disease refer to physiological changes in the host (chlorosis, necrosis,etc.), they also may include items such as market grade, protein, oil or nutritive content of the host or host product. Qualitative assessment is mainly used in resistance breeding.

There are, similar to insect pest assessment, methods of direct pathogen counting (**spore trapping**) and methods of indirect assessment (**disease assessment**).

It is, however, difficult to indicate individuals when considering a fungal population. Monitoring of fungi, therefore, has to be done in different stages of the development of the fungal population: for trapping individual propagules of fungi the sporulating stage is suitable, whilst for assessment of injury (=disease) the symptoms expressed through infection are used.

6.2.1 Monitoring plant pathogens

There are a number of well developed techniques available for collecting and counting pathogen propagules. Fungal spores, especially those which are airborne and produced abundantly, can be trapped by so-called **spore traps** of which quite a number of different types has been developed, which work quite accurately (e.g. Burkard spore trap). Techniques for monitoring low population levels, especially of splash dispersed organisms, are less well developed. Once collected, spore numbers can be counted either under a microscope or by the use of an automatic counting instrument, or indirectly measured by weight.

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BOX 6.2

Incidence refers to the ***number*** *of plant units affected, i.e. the number of leaves, fruits, ears, shoots, etc., expressed as percentage of the total number of units appraised. The incidence is expressed as a fraction: 0 < x > 1.*

Severity *refers to the* ***area*** *of plant tissue affected, either in particular organs or whole plants, expressed as percentage of the total area of plant tissue appraised. Severity is also expressed as a fraction: 0 < x > 1. There are several methods to determine the severity of a pest.*

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Many specific tests have been developed for pathogen monitoring for soil and seed-borne diseases, as well as for bacteria and viruses; however, they are not that simple to be employed directly by the farmer himself.

Spore counting and related techniques are useful for pathogen monitoring for the identification of disease risk periods, i.e. **forecasting** (chapt. 9), when inoculum potential is high. These measurements are especially useful if it is also possible to monitor meteorological conditions suitable for germination and infection (see also chapt. 7).

The most important disease where spore trapping plays a practical role is the scab of apples and pears (*Venturia inaequalis*). Other pathogenic fungi of which the control can be guided by trapping their spores include the downy mildews of hop (*Pseudoperonospora humuli*) and of tobacco (*Peronospora tabaci*).

But in general, spore trapping is not so used extensively by crop protection advisers or farmers for obvious reasons: (a) the equipment is not cheap and needs maintenance, (b) interpreting the catches requires considerable expertise (for instance, spores of many mildews and many rusts look much alike), and (c) many plant diseases are not suitable for spore trapping. Furthermore, measurements of pathogen propagules take no account of the their ability to cause disease, nor of the host plant reaction to a successful infection by a pathogen.

6.2.2 Disease assessment

In many situations disease assessment, based on symptoms, is more closely related to yield loss than the direct measurement of pathogen propagules. Many diseases (e.g. smuts, wilts, virus diseases) can easily be quantified by just assessing the **incidence**. However, the measurement of incidence is not sufficient where there is a quantitative relationship between the degree of infection, or **severity**, and the amount of yield loss. Thus methods have been developed for estimating disease severity. Most methods rely on the observable difference between healthy and infected tissues, quantified with varying degrees of accuracy and precision.

Field keys:

A field key is a **verbal** and **numerical** description of disease **severity** classes: A **disease scale** describes plants with different levels of disease and assigns a grade or percentage infection to each description. The scale of such a key (e.g. the classes of the different grades of severities) should be divided in such a way that disease severities can easily be differentiated. A field key must take into consideration not only the area covered by lesions, but also any defoliation caused by the disease. A total of seven or eight grades has been shown to give enough accuracy for monitoring purposes.
The classical example is the field key for the assessment of potato late blight (table 6.1).

Table 6.1. Field key for the assessment of disease severity of potato late blight on the haulm caused by *Phytophthora infestans*, (Zadoks & Schein, 1979)

This key has been designed for easy and rapid scoring of blight on the haulm in yield trials and farmers' fields, looking at the crop as such (British Mycological Society, 1947). Allowance is made for the recording of foci.

Blight (%)	Description
0	Not seen on field.
0 1	Only a few plants affected here and there; up to 1 or 2 spots in 12 yards' radius.
1	Up to 10 spots per plant, or general light spotting.
5	About 50 spots per plant, or up to 1 leaflet in 10 attacked.
25	Nearly every leaflet with lesions, plants still retaining normal form: field may smell of blight but looks green, although every plant is affected.
50	Every plant affected and about ½ of leaf area destroyed by blight: field looks green flecked with brown.
75	About ¾ of leaf area destroyed by blight: field looks neither predominantly brown nor green. In some varieties the youngest leaves escape infection so that green is more conspicuous than in varieties like King Edward, which commonly shows severe shoot infection.
95	Only a few leaves left green but stems green.
100	All leaves dead, stems dead or dying.

Note: In the earlier stages of a blight epidemic, parts of the field sometimes show more advanced decay than the rest and this is often associated with the primary foci of the disease. Records may then be made as, say 1 + pf 25, where pf 25 means 25% in the area of the primary foci.

Fig. 6.1: Sketches of lesions that are equal in size but quite different in effect on yield.
Left: potato with late blight (*Phytophthora infestans*)
Right: rice with blast (*Pyricularia oryzae*)

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BOX 6.3

A word of caution

Lesions of equal size do not necessarily have equal effect. A lesion of ***Pyricularia oryzae****, the rice blast, on the neck of the panicle, although equal in size to a lesion on the leaf, has a dramatically different effect on yield and crop loss. An early neck lesion prevents maturation of all seeds of the panicle; a single lesion on a leaf blade is virtually without effect (see fig. 6.1).*

In the same way, a stem lesion of potato late blight kills a haulm with 10 leaves and 50 leaflets, whereas the same lesion on a leaflet only kills the one leaflet at most. The instructions in the field key should, therefore, point out such problems and provide ratings.

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Many keys are based on the whole plant rather than on individual plant parts (e.g. potato late blight assessment key, wheat foliar diseases key, etc.). Their use, therefore, is most appropriate for the rapid visual assessment of a foliar disease on whole plants, in plots and in commercial fields: They are used a lot by plant breeders for screening cultivars and breeding lines, and by field scouts monitoring large commercial fields.

Disease response keys are a special form of a descriptive key, used mainly for assessment of diseases in plant breeding: The key describes several reactions types (or response types) of the disease, sometimes colour plates or standard diagrams can also be used, depending on the crop/pathosystem.

Standard area diagrams:

A logical development from the disease keys are the standard area diagrams as a guide to visual estimates of the area of **plant parts** occupied by a disease. Initially developed for symptoms on leaves (e.g. foliar diseases), the principle has been extended to other plant parts, including shoot buds, awns, ears and flowers, stems, fruits and roots. Some diagrams have been developed to describe the amount of disease on whole plants (e.g. for leaf blight of maize, *Drechslera turcica*).

Note: The principle of standard area diagrams is also applicable to injuries caused by insect pests.

A standard area diagram or *standard diagram* consists of a set of pictures giving a schematized illustration of the grades of severities distinguishable on the leaf (or other plant parts). The diagrams show typical disease (or injury) symptoms for a range of severities, often up to 50% of total area, and may also show the proportional distribution of leaf area as shown in fig. 6.1.

Standard diagrams can be developed using video image technology, computer based graphics,photocopies or simply by drawing the plant part and their different grades of lesions on graph paper. Fig. 6.2 shows such a standard diagram worked out for assessing severities of coffee leaf rust (*Hemileia vastatrix*).
Visual estimates of severities with the aid of standard diagrams by trained personnel are fairly reliable, particularly when the measurements are made without prior knowledge of treatment.
There are already many standard diagrams available for a wide range of crops and diseases such as those in the FAO and MAFF manuals (see literature list). There is, however, often a marked variation in the appearance of specific diseases in different locations and on different cultivars. But any diagram which depicts the observed symptoms is useful, whether or not it was designed initially for that purpose.

Diagrans represent 50 cm^2 coffee leaves illustrating rust lesions of 1, 3, 5, 7, and 10% of the total leaf area giving a cumulative lession-areas of 25 and 50%. Estimate rust intensities below 25% by making a cumulative count of the lesion-areas. At intensities above 25% estimate rust intensity directly as 25, 50%, etc. Any intermidiate level between 0-100% can be estimated with experience.

Os diagramas representam 50cm^2 de folhas, ilustrando lesões de ferrugem de 1, 3, 5, 7 e 10% da área foliar, dando uma área acumulativa das lesões de 25 e 50%. Estima-se a intensidade de ferrugem abaixo de 25% pelo somatório das áreas das lesões. Intensidades acima de 25% são estimadas diretamente em 25, 50%, etc. Pode-se avaliar qualquer nível intermediário entre 0-100%, após alguma prática.

Fitopatologia Brasileira 3: 119, 1978

ASSESSMENT KEY FOR PERCENT COFFEE LEAF AREA RUSTED

ESCALA PARA AVALIAR A PERCENTAGEM DE AREA FOLIAR COM FERRUGEM DO CAFEEIRO

A. C. Kushalappa
G. M. Chaves

Universidade Federal de Viçosa
Departamento de Fitopatologia
36570 - Viçosa - MG - Brasil

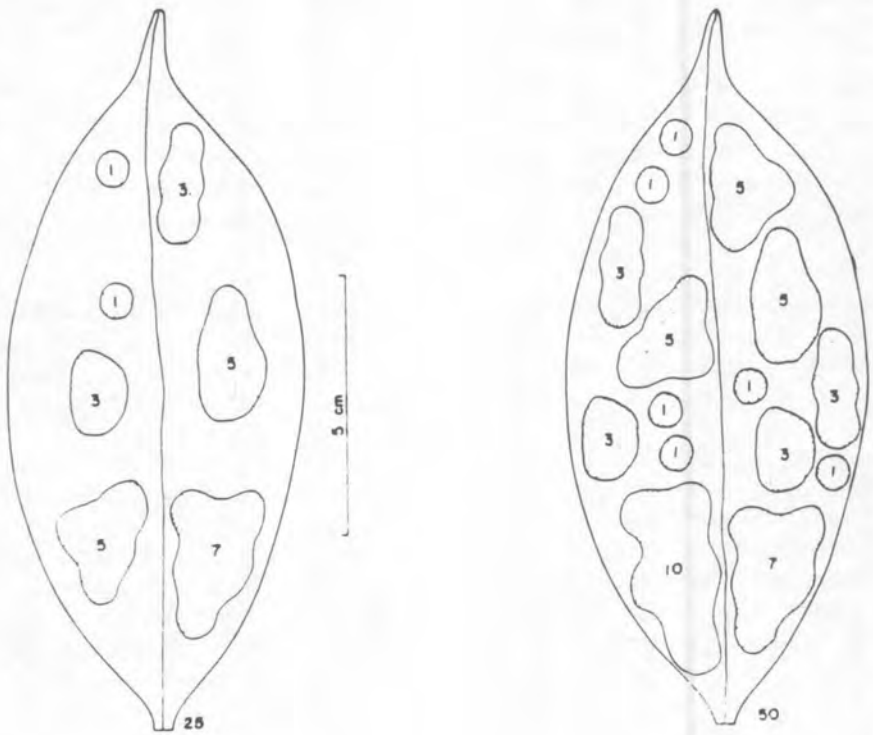

Fig. 6.2: Assessment key for coffee leaf rust (*Hemileia vastatrix*), Kushalappa and Chaves, 1978

Assessment techniques using standard diagrams are mainly employed in crop loss assessment experiments for detailed analysis of the relationship of the amount of physiological distrain and the resulting yield, as well as in studies on disease progress (epidemiology). As already mentioned earlier, assessment of severities is not so practical in pure monitoring work, where **incidence counts** are more convenient (quicker, easier, less bias); however, severity recording is indispensable for establishing reliable incidence/ severity-relationships. Only few control programs include monitoring of severities, like the control program of Sigatoka in banana (see detailed information, annex).
Proportional scales combining both incidence counts and severity assessment have been also tried out in crop loss experiments. However, they also seem to be quite error-prone.

Image analysis:

The lack of objectivity in disease measurement has provided impetus to the search for better technologies, including the use of video image analysis by computer and remote sensing. Remote sensing may be used as a measure of both disease incidence and severity; it is also applicable for insect pests. Remote sensing has been most useful with those diseases where infection is associated with a complete yield loss.

6.3 Monitoring insect pests

Pests can be counted **directly** on plants or in the environment, or their effects can be assessed **indirectly** on plants/crops as injury or damage.

6.3.1 Direct counts for assessment of absolute and relative population densities

Direct counts can be considered in two ways: (a) based on a standard unit, such as area of ground or weight of plant, or (b) converted to such a unit from the number of leaves, stems or plants per area or yield of crop.
Direct counts on **plants** provide an information about *absolute densities* of insect pests. Direct counts of insect pests in the environment, for example through a suction trap, also provide *absolute densities*, whilst through other types of traps (e.g. light traps), provide *relative densities* as an **estimate** of the absolute population. In all cases, the method must be representative or intended to give as true an estimate of the actual population as possible.

For the **estimation of absolute population densities** there are quite a number of methods worked out:

*a) **Direct counting on plants:***

- **Visual observation per unit of habitat**: the number of insect pests/plant part or per area/volume of soil is counted. The absolute population is obtained by multiplying up to the desired population.
- **Cutting open** fruits, seeds, stems: for stem borers, larvae in tubers and pods.
- **Crushing** or imprinting on gloss paper or ninhydrin paper: for aphids and mites.
- **X-rays**: of seeds for midges, of stems for borers, of gall for mites.
- **Beating**: of branches on a sheet of umbrella.

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BOX 6.4

The trapping efficiency is the percentage of the insect population present which is actually recorded. Trapping efficiency is largely influenced by biotic and abiotic factors: Increasing wind speed may mean reduce flight activity hence lower trapping efficiency. Full moon may result in lower attractiveness of light traps. Tsetse flies may show a distinct preference among various oxen used as mowing bait traps.
The trapping result will be a function of: (a) the response of the insect to the stimulus (physiology), (b) the activity (climate), and (c) the abundance (population density). These factors determine the availability of the insects for trapping. There may be a threshold level below which there is no activity or response.

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- Brushing: on to a sticky surface, by hand or machine, for small insects or mites.
- **Washing**: for small insects or mites, using a detergent, solvent, etc. (=measurement of pests by volume).
- **Knock down**: spraying plants with non-persistent chemical such as pyrethrum or dichlorphos and shaking insects on to a sheet.
- **Suction**: collection of all insects on a plant with a vacuum cleaner.

b) Direct countings in the environment:

- **Soil and debris sampling**: a standard volume sample is taken and insects are separated by fry or wet methods.
- **Emergence trap**: used to monitor the emergence of insects from the soil.
- **Sampling from the air**: through suction traps, used for a broad variety of insects.

c) Mark-recapture method

Populations of mobile insect pests in a limited environment can be estimated by marking, releasing and recapturing them (for detailed information see Southwood, 1978).

For the estimation of **relative population densities** for monitoring purposes a number of techniques are available:

a) Visual search per unit of time: This method is very suitable for monitoring, but caution has to be taken because of changes in the behaviour of pests with the weather and the age of insects, and because of differences among observers in their ability to spot and identify specific insect pests on a certain distance.

b) Catching is an effort to extract insects from their habitat. A typical catching device is a sweepnet, which is a very rapid, easy and cheap method to collect insects from **low crops**. The efficiency of the sweep net usually varies with different species, different habitats (e.g. height of the crop), different weather, particularly wind speed, air temperature and solar radiation, different time of the day, different styles of sweeping, etc. Thus, it is very difficult to standardize these method for collecting quantitative data on insect populations.

c) Trapping in its various shapes is one of the most important tools to make estimates of insect populations. Trapping is trying to establish a relative estimate of the size of the (active part of an) insect population by means of devices which are constructed to respond to and fit into the natural habitats of these insects.

By trapping in most cases only the active part of a given population is involved. This part is attracted to some physiological stimuli, such as light, sex pheromones, bait, shelter, colours. Other traps do not provide a stimulus but catch in a more random way insects which move freely around. Some traps are (very) specific (pheromone and bait traps), others are selective for a certain group of insects (yellow trap, pitfall trap, light traps).

6.3.2 Indirect methods of assessment of insect populations

Similar to plant diseases, estimates or counts of the **effects of insect pests** on the host plant population may be used to measure the amount of pest attack indirectly, in terms of injury and damage, sometimes taken as the simple visible effect. The **incidence** refers here to the number of plants or plant part infested by an insect pest, and **severity** (different from phytopathologist's view) refers to the degree of attack of infested plants only, without taking healthy ones into consideration.

The degree of infestation can be estimated in percentages or rated according to a numerical scale (as it is also done with diseases), but the latter method may be more difficult for statistical analysis. Small scale divisions may be difficult to separate, while, on the other hand, information will be lost if they are too big. Ratings always give less information than actual counts of percentages, and standard area keys are valuable for estimating areas of injury (see chapt. 6.2.2).

1. ***The whole plant:*** The number or percentage of plants missing or attacked (**incidence**) is recorded as a simple and quick measure, e.g. plants attacked by aphids, stemborers, root insect pests, etc.
   This method is very suitable for monitoring for decision making (see box 6.1 and practical no 5).

2. ***Leaves***: The area of leaf damage (holes, lesions, etc.) is estimated using a dot matrix grid , photography, light measurement, electronic scanning or by comparison with the undamaged leaf (standard diagrams). These methods are the same ones used for estimating **severities** of fungal diseases (chapt. 6.2.2).

3. ***Stems***: The number or percentage of dead hearts, exit holes, length of tunnels or nodes and internodes attacked by borers are used to assess pest populations in cereals and woody plants, e.g. number of lesions or stems cut by cutworms (*Agrotis, Mythimna)* or sawfly (*Cephus*).

4. ***Fruit and seeds***: Holes and lesions in fruit, damaged ears, cobs or seeds of cereals (e.g. whiteheads in rice), damaged cocoa pods, coffee berries or cotton bolls, etc. are suitable to assess indirectly the pest population, whereby the area of damage is measured.

5. ***Roots***: The length, dry weight or volume of fibrous roots attacked by soil insect pests can be measured or estimated from samples or sections. The area of damage to tuberous roots or stems such as potatoes or yams can be measured or compared to standard area diagrams.

6. ***Amount of by-product***: The quantity of excreta (stem borers), honeydew (aphids, brown plant hoppers) produced also has been used to assess insect pest populations.

ANNEX 6.1: Control programme of Sigatoka disease using data on severities (CHiarappa, 1973)

Date: 1973 **Host: Musa** (banana)
Organism: Mycosphaerella musicola (leaf spot, Sigatoka, black leaf streak *"M. fijiensis"*)

Method developed in: Honduras.

Field symptoms: Minute, yellowish-green specks less than 1.mm long appear first on leaves No. 2-4. In the case of black leaf streak and some strains of Sigatoka the streaks are rust coloured or dark reddish brown. The streaks broaden and increase in length to form a brown spot with a yellow to light brown halo. The spot becomes grey in the centre and is surrounded by a dark brown or black border sometimes with a yellow halo. In areas of mass infection, spots are reduced in size to black or grey streaks in a background of brown or grey dead leaf tissue. Leaf necrosis without spotting is extensive around areas of mass infection. Spotting is often heaviest in the apical portion of the leaf and along the edges. In areas of heavy infection the entire apical portion of the leaf turns brown or black and curls downward. Fruit produced in areas of heavy infection often has soft, yellow pulps.

Effect on crops: The major effect is on the fruit which softens or ripens prematurely. Where spotting is severe, fruit ripens and softens on the tree before reaching harvesting size. Where spotting is less severe, green, firms fruit ripens in transit often within a few days following packing. Ethylene thus produced can trigger ripening in adjacent "normal" fruit.

Procedures

Commercial surveys. Check banana blocks at fortnightly intervals, selecting at random and at either side of roads or cableways medium-sized, non-flowered plants. In large farms use a minimum sample of 50 plants per 8 hectare block, otherwise use 100 plants per section. On each plant, number individual leaves downward and consecutively from the youngest, unfurled leaf (No. 1) to the oldest, upright leaf (No. 12 to 14 on healthy, mature plants just before flowering). Assess disease intensity as follows:

(a) determine the presence (or absence) of "spotting" (minimum of 10 spots to classify leaf as "spotted").
(b) determine the position (e.g. number or age) of "spotted" leaves and record the number of the youngest "spotted" leaf.

Calculate and record:
(a) Percentage of plants with "spotting"
(b) Percentage of plants with "spotting" on leaves younger than No. 8
(c) Average number (or age) of the youngest leaf with spotting.

For guiding control operations (e.g. reducing sources of inoculum) it is also useful to record separately the areas most heavily spotted (no more than 5-10% of total area).

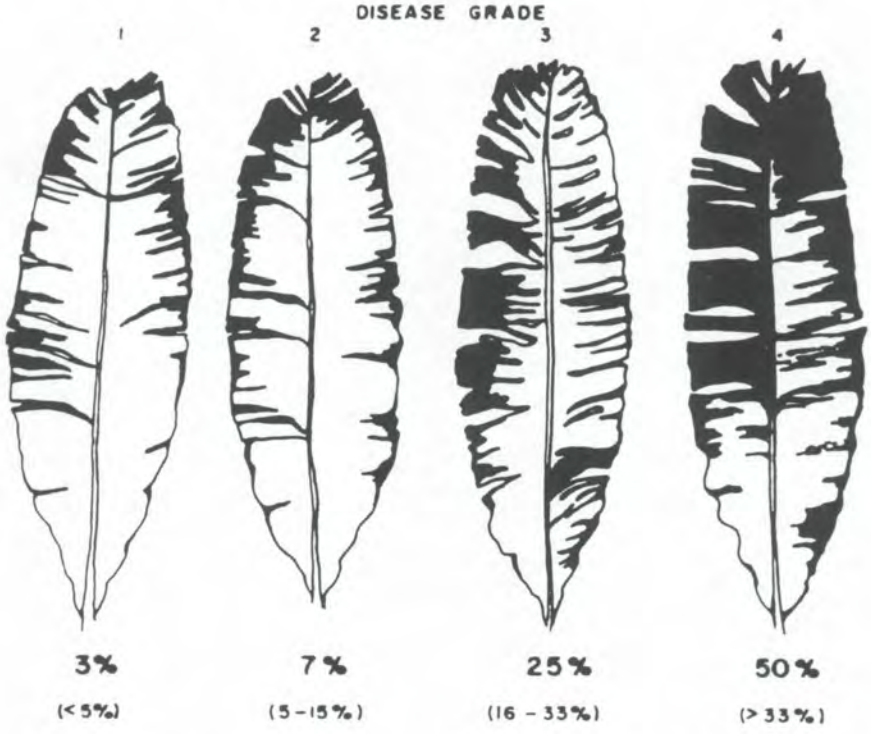
Research surveys. (For evaluating control methods or for determining effect of weather).

Where plots are less than 0·2 hectare (0·5 acre) take readings on 10 plants/pot at bi-weekly intervals and over a 4-6 months period. Make the same determinations as in (a) and (b) under "commercial surveys" and in addition determine the percentage leaf area spotted by assigning to each leaf a disease intensity grade (use keys shown overleaf).

Where leaf production cycle is greatly different from the usual 7-9 day cycle, report rate of new leaf production.

Intensity/loss relationship: The following disease levels have been experimentally correlated with fruit loss by establishing different degrees of control through manipulation of fungicide spray schedules:

BANANA LEAF SPOT ASSESSMENT KEY



Black areas represent the percentage of destroyed tissue as if all spots (or spotted areas) were fitted into one leaf portion. Numbers in parentheses indicate range of percentages.

after R H Stover - 1971

A	B	C	Fruit loss	
Average age of youngest "spotted" leaf	% plants with "spotted" leaves younger than leaf No. 8	% "spotted" plants	Field	Transit
10-12	10	40	None	None
8-9	40-60	100	Up to 10% culled as ripe	Up to 20% of fruit ripens or colours within 7 days
5-7	60-80	100	Up to 75% culled for soft fingers or yellow pulp	Over 50% of fruit will ripen or turn colour within 7 days

NOTE: These data were obtained on highly fertile Central American loams with export yields of 45 to 54 metric tons of fruit per hectare per year. Injurious levels of spotting will likely vary with less favourable ground conditions.

Limitation or prevention of damage: In Central America and under favourable growing conditions most damage is prevented when the following minimum disease values are obtained through control measures:

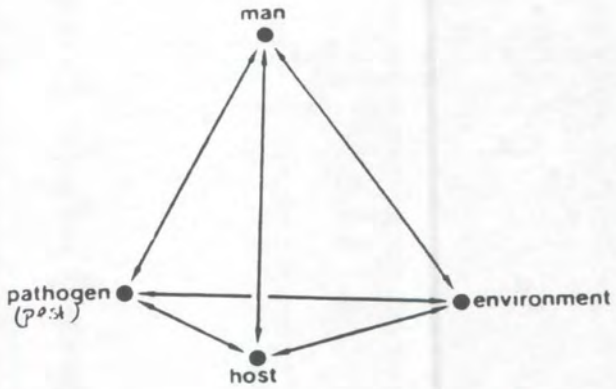
A	B	C
No less than No. 9	No more than 20%	No more than 60%

To achieve these values an oil-in-water emulsion with a maneb fungicide or benomyl added is applied every 3-4 weeks or longer depending on weather. The best coverage and control are obtained with aircraft application although control can be obtained with spray applied from the ground. Good coverage is essential for good control.

Sources

1. Stover, R.H. 1971. Banana leaf spot caused by *Mycosphaerella musicola:* contrasting features of Sigatoka and black leaf streak control. *Plant Dis. Reptr.* 55:437-439.
2. Stover, R.H. 1971. A proposed international scale for estimating intensity of banana leaf spot. *Trop. Agric. Trin.* 48:185-196.
3. Stover, R.H., and Dickson, J.D. 1970. Leaf spot of bananas caused by *Mycosphaerella musicola:* methods of measuring spotting prevalence and severity. *Trop. Agric. Trin.* 47:289-302.
4. Stover, R.H. 1973. Effect of measured levels of Sigatoka disease of bananas on fruit quality and leaf senescence. In press. *Trop. Agric. Trin.*

Summarized by: R.H. Stover
Division of Tropical Research
Tela Railroad Co. (a subsidiary of the United Fruit Company)
La Lima, Honduras, C.A.



Graphical expression

Fig. 7.1 Pest tetrahedron with pest/disease triangle showing the interrelationships

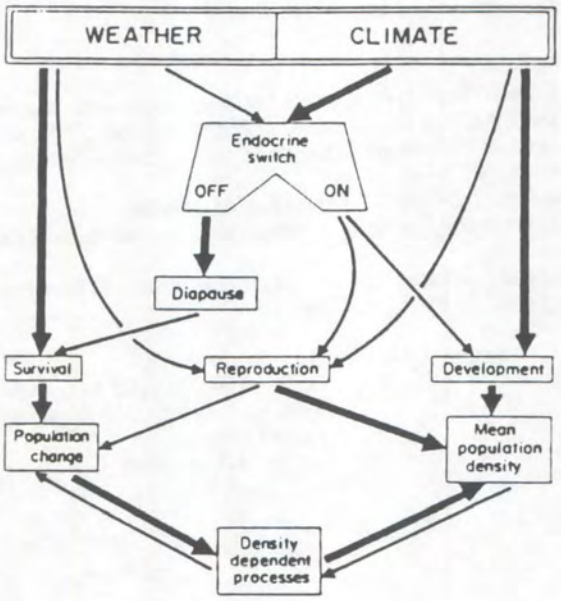


Fig. 7.2 A diagrammatic presentation of the main effects of weather and of climate on an insect population

7. MONITORING THE ENVIRONMENT

7.1 Importance of environmental factors for pest development

Integrated pest management is concerned with the interactions of host and pest populations that lead to injury, damage and crop losses. These interactions are environmentally dependent. Symbolically, this has been depicted in the pest triangle, which is the base of the pest tetrahedron (fig. 7.1): The environment influences both the host and the pest; host and pest affect each other. The host often changes the environment, but the pest rarely does so. At the top is man, who is manager and subject at the same time. These four elements mutually influence each other, but the various influences are not equally strong at all levels of integration.

The processes and sub-processes of pest development enrol in the environment as a whole. For the purpose of identification of specific areas of interest, however, some sub-divisions of the environment can be considered:

The environment is delineated in terms of *space*, *time* and *quality (species composition = diversity)*. The total of biologic species known to influence pest development is called the *biotic environment* (e.g. weeds, parasites, predators, competitors, N-fixing bacteria, etc.), whilst the total of non-living influences on the development of pests forms the *abiotic environment* which in its turn is divided into the *physical* (e.g. weather) and *chemical* (e.g. pesticides) *environment*.

Spatial aspects:

1. The microenvironment is the space in which the developmental processes at cell and organ level occur.The *phyllosphere* is a ca. 1mm thick area around the leaf, whilst the area around the roots is called the *rhizosphere*.

2. The mesoenvironment is formed by the crop, which per definition is a collection of plants, basically with the same genetical background, grown by man in an aggregation of some sort (monoculture or polyculture). The crop has certain characteristics (crop density, leaf area, crop structure) which influences the microenvironment.

3. The macroenvironment comprises the air layer from the crop surface to the troposphere. Some epidemiologically important processes occur in the macroenvironment (e.g. the long distance dispersal of cereal rusts, flights of insect pests, etc.). Meteorological phenomena at a larger scale greatly influence the environment at a smaller scale.

Temporal aspects:

The environment changes in time; a distinction between micro-, meso- and macro-scales is useful when referring to distinct development processes: Most spore liberation phenomena occur at the *microscale* measured in seconds.
The *mesoscale* comprises phenomena completing their course in periods ranging from one hour to one day, like spore germination and penetration.

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BOX 7.1 CLIMATE AND WEATHER

Traditionally, *climate* is defined as a statistical summary of atmospheric (environmental) conditions (temperature, precision, etc.) typical for a given location, and *weather* is defined as the actual atmospheric (environmental) conditions prevailing at a given site and time.

Nowadays, it is more common to define climate as a dynamic physical system that produces weather. *Macroclimate* is the climate or prevailing conditions that occur over a range of 50-1000 km and is characteristic of global regions. *Mesoclimate* occurs over a range of 100 m to 100 km and is characteristic of a specific landscape.
Microclimate has a range of 1 mm to 300 m but usually is concerned with the meteorological situation of a plant cover or plant canopy.

With reference to plant disease epidemiology and population dynamics, macroclimate has an influence not only on what type of hosts will be found in a particular geographic area, but also on the pests of a particular host that will occur within a given geographic area. For example, sclerotium disease (caused by *Sclerotium rolfsii*) occurs on vegetable and field crops in the southeastern United States, but is seldom found in the northern states. The potential hosts of *S. rolfsii* are able to grow in the cooler northern climates, but the pathogen does not survive the cold winters.

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The *macroscale* is adjusted to the vegetation season of the crop and is measured in days, or, with slow processes and perennial crops, in weeks, months or years.

Qualitative aspects:

The quality of the environment in biologic terms is described by the concept of *diversity:* It is used to characterize an environment by means of the number of species and the number of individuals per species living in that environment. Diversity of the environment implies that many species live together in one area and interact.

Biotic aspects:

The species other than the host-pest pair under consideration together form the biotic environment of that pair. The effect of other microorganism and species in the pest environment may be positive, negative, or neutral (examples: N-fixing bacteria and blue-green algae, hyperparasites, predators, etc.). Sometimes the biotic environment is pest limiting, as in the case of *Mycospherella musicola*, causing Sigatoka disease of bananas, which can infect only within 1 or 2 days after leaf unfolding, before a phyllosphere flora has built up.
The assessments of the effects of predation, parasitism and competition form the basis for biological control which in the case of insect pests is functioning quite well in many cases, but which has not yet reached practicability at greater scale in the case of fungal and bacterial diseases.

Abiotic aspects:

The abiotic aspects comprise the *physical* and *chemical environment*. The chemical environment of the pests is studied and described in detail in the discipline of the physiology of parasitism. However, side effects of pesticides are also somehow part of the chemical environment and may influence crop and other pest development (e.g. phytotoxicity, tonic effects, pollution).

Out of the physical aspects of the environment the *weather* or *climate* is one of the most influential factors on pest development: The microclimate within and around a crop is affected by the weather which in the end is affected by the climate of the region. Most activities of pest populations take place in a crop, so, these activities are affected by the microclimate of the crop. The type of crop, on the other hand, influences itself the microclimate: crop structure, crop density and leaf area influence humidity, radiation, temperature, etc. within a given crop.

Environmental factors can vary from place to place and from time to time. Fungi and insects have to be very flexible to survive. This flexibility has its limitations and can end into the death of the insect/fungi or into a decrease of its rate of development. The latter can, for instance in the case of microclimate, be exploited by means of cultural practices.

Climatic factors are the most important among the **environmental factors** that affect pest development: **weather** and **climate** influence the pest development either by interacting with the pest and/or by altering the host physiology. Optimal climatic conditions for many pests are known by now.

Fig. 7.3 Liquid-in-glass thermometers. A, Maximum-minimum thermometer; B, -2- to 110 °C thermometer

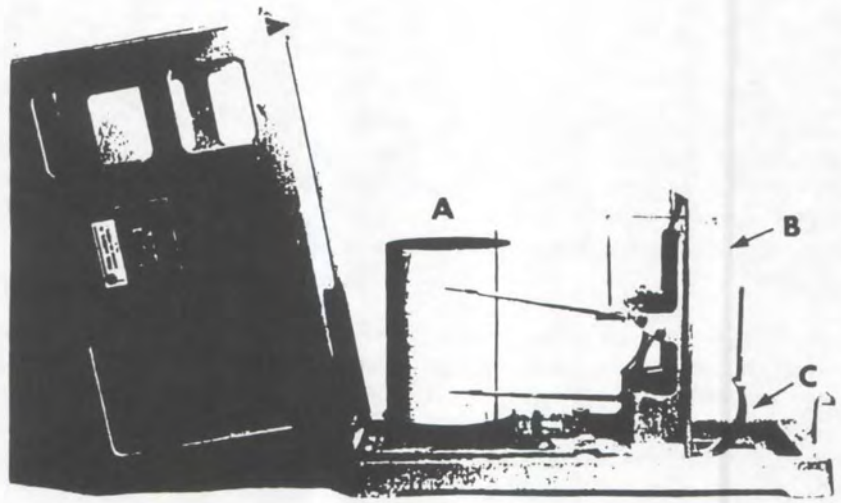

Fig. 7.4 Hygrothermograph with deformation (filled-system) thermometer (C) and hair hygrometer (B). Changes in sensing elements are translated mechanically to recording pens on rotating strip chart recorder (A)

The climatic parameters can easily be quantified and monitored, even in many cases automatically through meteorological equipment. This is made use of in detailed studies on epidemiology and population dynamics as well as in forecasting and advisory systems.

7.2 Meteorological variables and their measurement

The meteorological (weather) variables of interest for pest development include temperature, moisture (rainfall, relative humidity, leaf wetness, dew), radiation and wind (table 7.1 and fig. 7.2). Each of these quantities can have profound individual and interactive influences on the initiation and progress of epidemics and pest infestation. Although for clarity and simplicity we consider each meteorological variable separately, their effects seldom occur separately or independently. Very often one or only few climatic factors can account for the effects of other factors involved or compensate them (example: sunshine-rain, humidity-temperature).

7.2.1 Temperature

Temperature is the environmental variable *most often* correlated with biological responses. Temperature is one of the fundamental variables governing the rate of reproduction of nematodes such as *Meloidogyne* spp., the maturation of pseudothecia in *Venturia inaequalis* (apple scab), and the reproduction of *Erwinia amylovora*, the causal agent of fire blight.
As far as insect pests are concerned, temperature is of major importance as it accelerates or slows down their emergence and passing through developmental stages. This dependency is exploited by means of *temperature sums* or *day degrees* when forecasting pest development (see also chapt. 9).
In the case of fungal diseases, temperature has an effect mainly on infection, sporulation, incubation time, lesion development and also on survival. Especially, the temperatures during leaf wetness may be decisive for initiating fungal development (germination, infection), this in difference to insect development.

Measurement of temperature:

In crop-weather relations, the temperature of the soil, the plant canopy and the surrounding air are important. Because of the gradients and different thermal characteristics of air, soil and plant materials, the temperature of the air in the plant canopy may differ from that of nearby leaves or stems or from that of liquid water on a leaf surface. Due to this, useful temperature data depend on the measurement of a representative temperature. That means in practice that soil temperature has to be registered separately from air temperature.

For measuring temperatures in plant protection work principally three types of thermometers are used, grouped according to their construction:
(1) The *liquid-in-glass thermometers* are probably the most widely used temperature sensors (see fig. 7.3), recording maximum and minimum temperatures;
(2) The *deformation thermometers* use bimetallic strips which expand differently according to their different thermal coefficients of expansion;
(3) The *electric thermometers* (mainly two types of sensors: thermocouples and thermistors) are well adapted to automatic recording and very useful for remote or unattended monitoring. They are used nowadays widely in conjunction with microprocessor-based data loggers.

Table 7.1 Critical phases in pathogen's life cycles and weather factors as possible predictors

Critical phases in life fungal cycles	Weather factors affecting	Units of measurement (1)
Infection (except powdery mildews)	- Leaf wetness (dew, rain, fog, RH, irrigation), - Temperature - Relative humidity (RH) - Light	Hours with leaf wetness per day, week etc. - Temp. °C during hours of leaf wetness, or high RH - Number of hours with RH > 90% per day, week, etc. - Hours with sunshine per day(s) or week; g.cal/m^2/min.
Incubation and latency period	- Temperature	- Sum of daily main temperatures in °C
Inoculum production and dispersal (except powdery mildews)	- Leaf wetness - Temperature - Light - Wind - Rain	- Hours of leaf wetness/day, week, etc. - Hours of windspeed (in ms/see) beyond a threshold - Intensity (mm/h), number of hours or day with rain in a given period of time
Disease progress	- Temperature - Leaf wetness - Rain - Light	Same predictors as with infection and incubation
Survival	- Temperature - Wetness - Light	- Sum of temperature (with or without basic temp.), number of hours below minimum or beyond maximum temp. - Wetness criteria - g.cal/m^2/min. per day etc.

(1) Examples only; other units may be found appropriate

7.2.2 Moisture

Atmospheric and soil moisture can have profound effects on the development of plant pests, vectors and host plants (growth), and thus on epidemics and pest infestations. Moisture as an influential variable for pest development is measured mostly as relative humidity, leaf wetness, rain, dew and soil moisture. Moisture in form of relative humidity and leaf wetness is more important for the development of fungal diseases and bacteria, whilst rain plays an important part in the dispersal and washing-off of smaller insect pests like aphids.

For the majority of diseases the main factor affecting the very critical and important phases of infection and sporulation is **leaf wetness**. Leaf wetness can be due to rain, dew, high relative humidity or fog, each having additional specific effects which sometimes have to be considered (e.g. in some diseases only leaf wetness emanating from rain is conducive to infection). Rain not only provides for leaf wetness and high relative humidity but can also be involved in the dispersal of fungal spores and bacteria.

Measurement of moisture:

1. Relative humidity

Relative humidity (RH) refers to the ratio of actual vapour pressure of the air/saturation vapour pressure which the air can hold at the given air temperature and atmospheric pressure. In general, the relative humidity in the field is low when the temperature is high and vice versa. This happens because the actual vapour pressure does not change very much but the saturation vapour pressure drastically changes with air temperature. *Hygrometers* are the devices commonly used to measure water vapour content of the air. *Hygrothermographs* are instruments which measure and record both air temperature and relative humidity (fig. 7.4).

In general, there are 5 types of hygrometers: (1) psychrometers which involve measurement of dry-and wet-bulb temperature; (2) instruments whose sensors (e.g. human hair) change physical dimensions upon absorption of moisture such as the hygrograph; (3) instruments involving condensation of water film: (4) instruments involving change in chemical or electrical properties of sensor upon absorption of water; and (5) instruments which depend upon absorption spectra of water vapour such as infrared gas analyzers.

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BOX 7.2 Importance of moisture for plant pathogens

The life cycle of most plant pathogens contains one or more phases that are affected by the states, forms and energy of environmental water:
Rain drops hit the plant with a certain impact, which is so great that dispersal of fungal spores and bacteria is induced. Most fungi that produce spores in pycnidia or acervuli (as well as some other fungi), are dispersed by rain splash (examples: *Phytophthora cactorum* on strawberry and *Phomopsis longicolla* on soybeans). In other cases (such as *Phoma* spp.) rain is the principal agent responsible for removal or washing-out of spores from the atmosphere.
Free water, once on the leaf surface, can have many effects on fungi: It can induce or stop spore production and spore germination: Most fungal spores need free water for their germination, but conidiospores of powdery mildew (*Erysiphe graminis*) are often inhibited by free water on the leaf.

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2. Leaf wetness

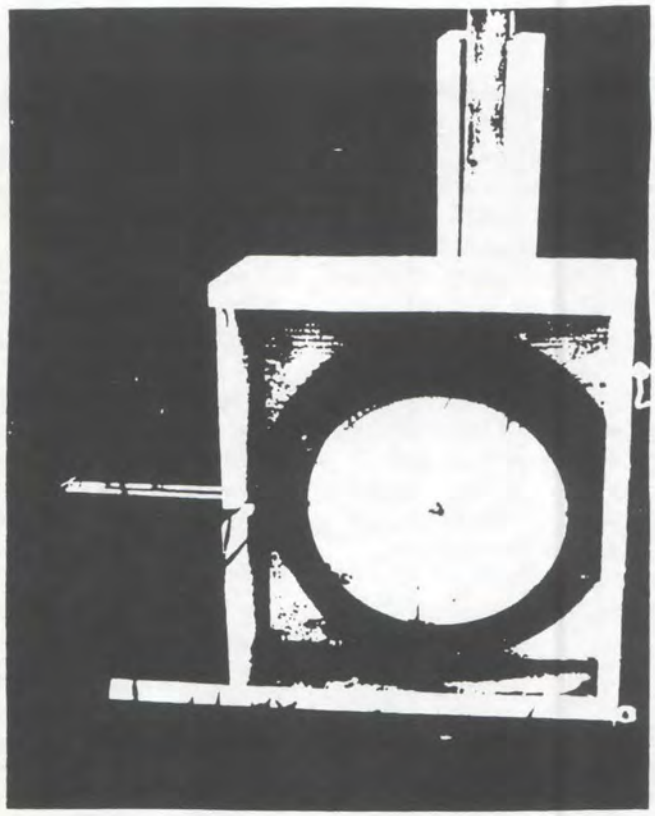
Leaf or plant surface wetness from dew, fog, guttation, irrigation, or rain affects epidemics caused by most foliar pathogens and is a **key element** for many disease forecasts (chapt. 9). *Duration of leaf wetness* is usually more important than the actual amount and form (e.g. droplets, film) of leaf wetness, especially for germination processes. The measurement of surface wetness poses several problems: The data on leaf wetness are meaningful only if taken within the crop canopy. Because of the morphological characteristics of plants and the structure and density of plant canopies, variations may be encountered even within the canopy. Another problem is that the plant surface wetness is measured only indirectly through a sensor which may not have the same physical and chemical characteristics as the plant organ of interest. The result is that the artificial surfaces may react differently which may lead to differences between actual and measured plant surface wetness. These limitations of measuring surface wetness have to be taken into account when planning monitoring leaf wetness and interpreting the recorded data.

There are 2 types of instruments measuring plant surface wetness: (1) *Mechanical instruments* (like the *deWit leaf wetness recorder*) which use a hemp string that expands when wet, and the changes in its length are recorded on a chart (fig. 7.5); and (2) *electronic instruments* with electrodes attached directly to the plant surface.
Predicting surface wetness: Sometimes wetness sensors are not available, yet an estimate of wetness duration is desired. Traditionally, hours of RH $\geq$ 90% have been used as such an estimate. This prediction is, however, inaccurate for dense canopies such as grain crops but fairly accurate for sparse densities (of low leaf area index), which are more common with many fruit and vegetable crops. If one wants to predict routinely wetness duration from other variables, a calibration study would have to be done first.

3. Precipitation

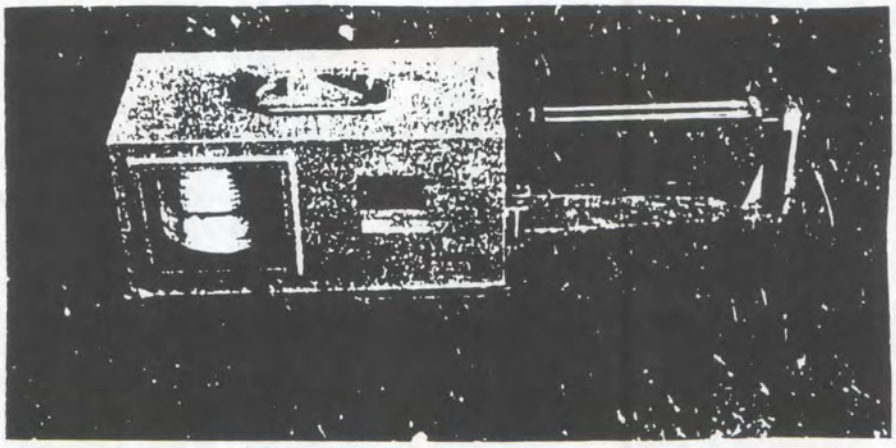
Precipitation is a general term for all water particles that fall on the earth's surface (like snow, hail, rain, drizzle). In the tropical lowlands, precipitation is almost synonymous with rainfall. For crop production and protection, not only the total amount of rainfall is important but also the intensity and duration of rain. Rain not only provides for leaf wetness and high relative humidity, but can also be involved in the dispersal of fungal spores and bacteria and, on the other hand, as already mentioned above, may cause, in form of heavy rain showers, the washing-off of airborne fungal spores and smaller insects.

The quantity of rainfall in an observation period is specified by the depth of water collected on an horizontal area. The standard instruments for measuring rainfall are the *rain gauges*, with cylindrically shaped funnels in which the water is collected (fig. 7.6). There are non-recording rain gauges which just collect the rain and have to be emptied daily, and the (mechanically working) *weighing rain gauges* for continuous weekly records (pluviographs) or the more sophisticated electronic working *tipping-bucket rain gauges* which can be connected to data loggers.



A

Fig. 7.5: Mechanical instruments for measuring duration of leaf wetness
A = de Wit leaf wetness recorder



B

B = Woelfle-Fuess wetness recorder

7.2.3 Other climatic factors

Wind influences the development of plant pests by transporting inoculum of plant pathogens and vectors from one location to another within and among crop canopies and among fields, states, countries, and even continents (famous examples: wheat rust spores and coffee leaf rust spores). Wind is also important in modifying the microclimate, i.e. temperature and moisture available at the leaf surface, within the crop canopy, and to a more limited extend, in the soil. Movement of plant parts by wind also causes abrasions to plant surfaces that may serve as entry sites for pests.

Movement of air in and above plant canopies can be described in terms of mean horizontal speed, direction and turbulence phenomena such as gusts and eddies. Although turbulence is an important factor, particularly in release and dispersal of inoculum, usually only mean wind speed and direction is measured and monitored.

The principal instrument for mechanical registration of wind speed and direction is the *cup anemometer* (fig. 7.7), which can register a whole month continuously and which is also available for use with data logger systems.

Solar radiation (light) is one form of an energy flux. Radiation comes in from the atmosphere, is modified by the atmosphere, and is partly reflected to the atmosphere again. There are certain wavelengths of the total radiation which are important for the development of insect and fungi:
-short-wave radiation (400-1000 nm) with more physiological effects on insects, fungi and plants;
-long-wave radiation (1000-15000 nm) as *thermal radiation* with effects on the energy budget of the plant and the pathogen/insect environment.
The length and the periodicity of the exposure to certain radiations may be of influence on these processes. *Light* may affect sporulation (coffee leaf rust sporulates more in pustules exposed to light) and pest development. In terms of sunshine hours per day, it is inversely correlated with relative humidity and may replace this criterion as its measurement is less error-prone.

Quite a number of specialized instruments are available for measuring solar radiation: The most simple instrument is the *Campbell-Stokes sunshine recorder*, which records the duration of sunshine only (fig. 7.8). The instruments most commonly used to measure the fluxes of the direct and diffuse solar radiation are known as *pyranometers*, working with sensing elements like thermopiles or photocells, which also can be connected to automatic data loggers.

The monitoring and measuring of solar radiation is done, until now, mainly for research purposes; besides the fact that is is quite difficult to measure accurately the irradiance or radiant flux incident on a surface per unit plant area, this meteorological variable is of minor importance for practical pest control in the sense that it is not easily exploitable for monitoring and forecasting purposes. The same applies to the variable wind.

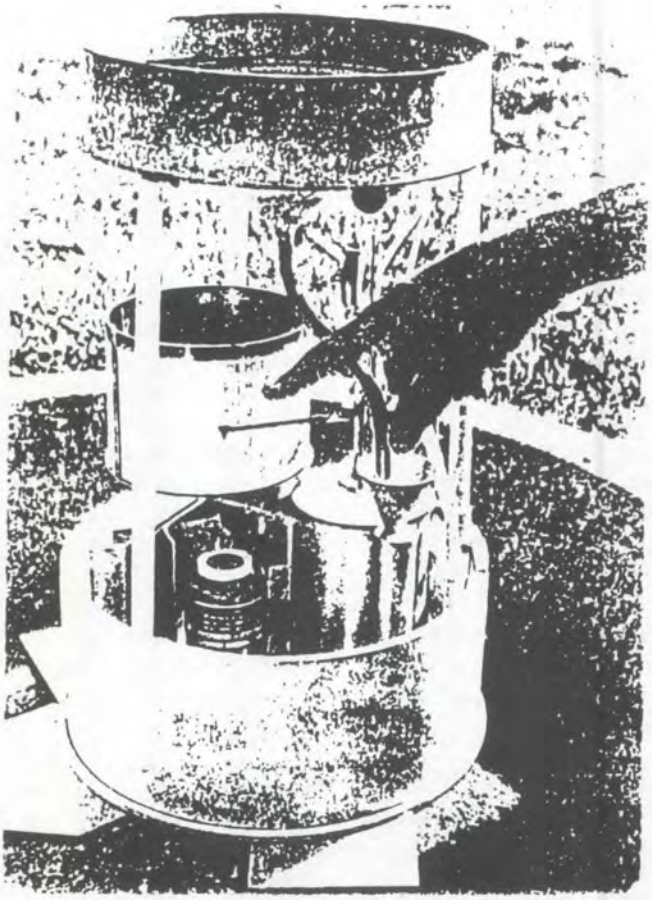


Fig. 7.6 A pluviograph: weekly recording of rainfall

Fig. 7.7 A standard cup anemometer registering wind speed and direction

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BOX 7.3 ATTENTION:

With very few exceptions, prediction schemes based essentially on temperature and humidity factors have as their aim the prediction of diseases that affect crops under the conditions of temperate regions, mostly unirrigated crops. Under such conditions, the temperature and humidity regime of many fields in a given region can be uniform enough to facilitate *regional forecasts* applicable to all or most of the fields with a particular crop. In recent years, however, *field-specific* forecasts have become possible by the introduction of systems such as BLITECAST (see box 7.4) where recording equipment placed by the farmer in his field is used to report to a central computer which then issues a warning applicable only to that field, if conditions there favour disease outbreak. If similar equipment becomes available in tropical and subtropical regions, it could probably be used to forecast many more pests that cause losses in these regions.

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7.3 Practical use of weather data for IPM

Due to the fact that climatic factors influence the speed of pest development, their monitoring might be used to forecast the appearance and development of a given pest. For some economically important parasites schemes have been worked out, mostly in temperate countries, to predict either the period in which they will *not* appear (negative prognosis), or to predict critical (infection) periods. This type of forecast, of course, is much easier in regions with drastic changes in climate (e.g. from winter to summer temperatures, rainy to dry season, etc.). Negative prognosis and forecasting on regional scale is possible only where (a) regional weather parameters can be measured and processed efficiently, and (b) crop conditions are reasonably uniform in all that relates to plant development (growth stage, density) and environmental factors (leaf wetness, irrigation), or in cases in which such factors can be recorded in the fields of individual growers. There are some internationally recognized examples of monitoring weather data for decision making in IPM (see box 7.4).

The fact that weather changes in time and space and further more the existence of macro-, meso- and microclimate complicate the use of weather criteria for forecasting purposes on a region or countrywide level. In addition, particularly due to these local deviations, the use of weather data to forecast pest events demands a sometimes rather dense network of agricultural weather stations, or weather equipment in the hands of farmers that need maintenance and proper understanding as to how to handle them, especially when referred to the necessary calibration, and to utilize their information.

As a rule, the meteorological station should be located in a site which is representative of the area for which the observations are made, at or near the centre of a cultivated area, surrounded with a fence, free from waterlogging, accessible even during wettest weather, and not obstructed by adjacent high hills, tall trees, buildings, or large irrigation canals. Although normally standard meteorological measurements from high weather huts (2.5 m above ground) may be used, in some cases screens with standard equipment (hygrothermograph) placed in between rows may give better predictions on farm level.