AGROMETEOROLOGICAL INFORMATION FOR PLANNING AND OPERATION IN AGRICULTURE

WITH PARTICULAR REFERENCE TO PLANT PROTECTION

Calcutta, India, 22-26 August 1988



GENEVA 1989

Editors

V. Krishnamurthy and G. Mathys

LECTURES PRESENTED AT THE WORKSHOP ON AGROMETEOROLOGICA INFORMATION FOR PLANNING AND OPERATION IN AGRICULTURE (WITH PARTICULAR REFERENCE TO PLANT PROTECTION)

Calcutta, India

22-26 August 1988

Geneva, 1989

Reflections on rainfall and wetness on leaves[1]

D.R. Butler[2]

Abstract

Water affects most leaf fungal diseases at some stage in their life-cycle. Estimates of leaf wetness persistence are important to epidemiology and methods for providing routine estimates are sought.

In certain climates good relationships can be found between the time that wetness starts and its duration, but usually the situation is less predictable. Wetness duration after rain is dominated by the amount of water held on leaves and the way that it is held (e.g. as discrete drops or as a film). The amount of water on the surface will depend not only on the amount of rain, but on the interception efficiency and leaf water holding capacity. These values depend on rainfall intensity and wind speed.

---

[1]Submitted as Conference Paper No. 484 by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for the Workshop on Agrometeorological Information for Planning and Operation with Particular Reference to Plant Protection, cosponsored by the WMO, 22-26 August 1988, Calcutta, India.

[2]Principal Microclimatologist, Resource Management Program, ICRISAT, Patancheru P.O., Andhra Pradesh 502324, India.

Introduction

When one asks the question "how does weather affect plant diseases?", it soon becomes apparent that the influence of water is often crucial to pathogen activity. Other elements of the weather cannot be ignored, but pathologists have for many years included leaf wetness with climatic variables to indicate the likelihood of changes in disease levels in crops. Because of its importance, leaf wetness is often measured in epidemiological studies but, in practice, it is difficult to utilize resulting relationships between pathogen behaviour and wetness for predicting disease. This is because leaf wetness is not normally measured as a routine weather variable and estimates of wetness duration are not commonly available. Sometimes leaf wetness is substituted by other elements of the weather which can be obtained from routine meteorological records such as humidity or rainfall, but disease-weather relationships which result are often not reliable. This is because good relationships do not always exist between these weather variables and leaf wetness duration.

Here we will examine the need for estimates of leaf wetness duration and discuss some factors which affect these when wetness results from rain water.

Disease life-cycles

I would like to begin by reminding you of the different phases in the life-cycle of fungal diseases. These are referred to in another part of these proceedings by Dr. Payen. Some environmental variables which could be associated with each phase are shown in Figure 1. Actual relationships are specific to the pathogen and host and the number of variables shown has been restricted to emphasize the importance of water.

The first phase is sporulation, that is the production and release of spores by fruiting bodies. Water is frequently required for the production of spores and their release is often brought about by a change from wet to dry conditions. Alternate wet and dry periods therefore commonly favour sporulation.

The second phase is dispersal. Fungal spores are commonly transported by air currents either dry or in extremely small "aerosol" drops of water. These spores may be deposited on the host either by impaction or sedimentation. An alternative method of dispersal is by splash, when relatively large water drops with high kinetic energy strike a surface containing spores and these are carried in droplets which are large enough to have definable trajectories and may impinge on healthy tissue of the host.

The third phase in the life cycle is retention when spores are held on the surface of the host. Some splash spread spores are carried in mucilage which acts as an adhesive to prevent washing off. Washing off is also avoided when spores are deposited on the underside of leaves. The retention of water drops (which may carry spores) on leaves will depend on the wettability of the leaf.

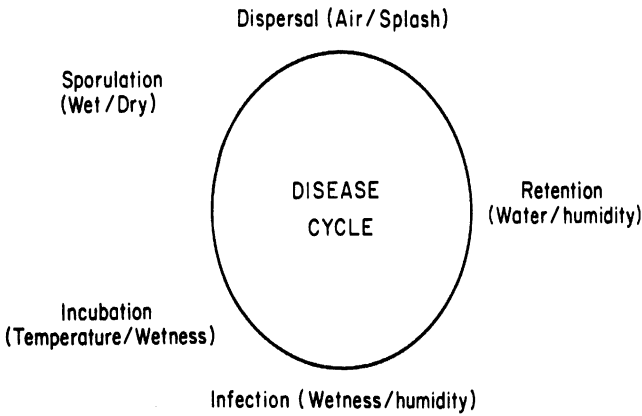

FIG. I. Life cycle of fungal diseases.

The fourth phase is infection, when spores germinate and a germ tube penetrates the host. This process is very commonly dependent on the presence of free water on the surface, the required duration of which is temperature dependent. The incubation period is the time between infection and sporulation and is primarily temperature dependent, however for some diseases there is evidence that wetness can influence disease progress and symptom severity during this period (Eyal et.al. 1977).

Overall it is apparent that water may be involved to some extent in every phase of the disease life cycle, so the persistence of wetness on leaves is likely to be critical to many disease epidemics.

Leaf wetness duration

The duration of leaf wetness depends on the environment and in certain climates straightforward relationships can be obtained to predict the persistence of surface wetness on particular crops. For example on cocoa pods in the Rondonia region of the Amazon Basin, Brazil, the duration of wetness is linearly related to the time of the start of wetness after 12 noon (Fig. 2). The relationship holds because the time that the pods dry is about the same each morning (0930 h) and any water from rain after midday will persist through the night. In this region sunny conditions are normal each morning and the majority of storms occur after midday. A very similar relationship has been published for coffee leaves in Colombia (Guzman and Gomez 1987). The group of points in Fig. 2 which indicate that wetness began

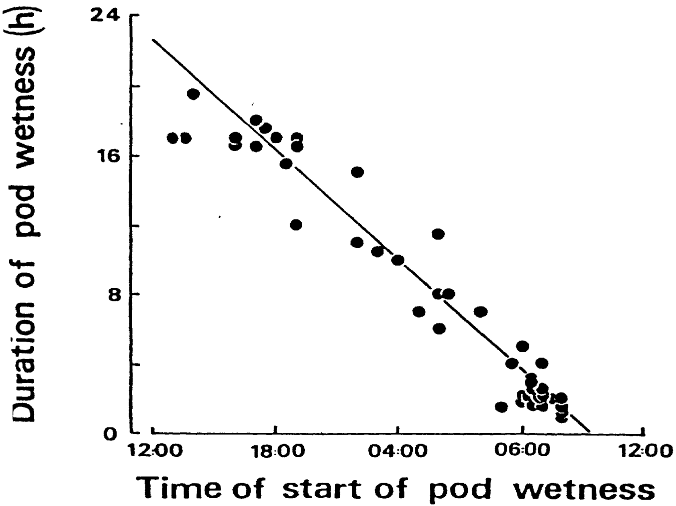

Figure 2. The duration of wetness on cocoa pods in Rondonia, Brazil in relation to the time of start on pod wetness. The diagram is reproduced from Rudgard and Butler (1987).

after 0600 h depict times when condensation formed on the pod surface (Butler 1980).

In most climates such convenient relationships to predict surface wetness duration are not found because the patterns of rainfall and sunshine are more varied. I now wish to consider two rainfall events, either of which could be expected to occur in monsoon climates, as we have heard in Dr. Mandal's paper (these proceedings). The first (Fig. 3) is a tropical storm with a thick convective cloud and large drops with high kinetic energy. The second is continuous light rain which could result from continuous cloud cover associated with a depression. In each case I have depicted a man with an umbrella; the first in the tropical storm is not happy because he is getting wet from the splash as large, high energy drops hit the ground around him. The second is much happier, because he finds that his umbrella is quite effective at keeping him dry and, as yet, he has not realized how long the rain will continue. Assuming that the total daily rain in both cases is 10 mm, what are the differences between the two situations? The tropical storm would only last say, 10 minutes so the rainfall intensity would be 60 mm h^{-1}. In the light rain the duration would be say, 5 hours so the intensity would be 2 mm h^{-1}.

Now consider the destination of rain in these two situations as it falls on a crop. When the intensity is large we would expect the efficiency of interception of water to be low because drops would strike the leaves with force and shake most of the water from their surface. Runoff from the soil surface would be

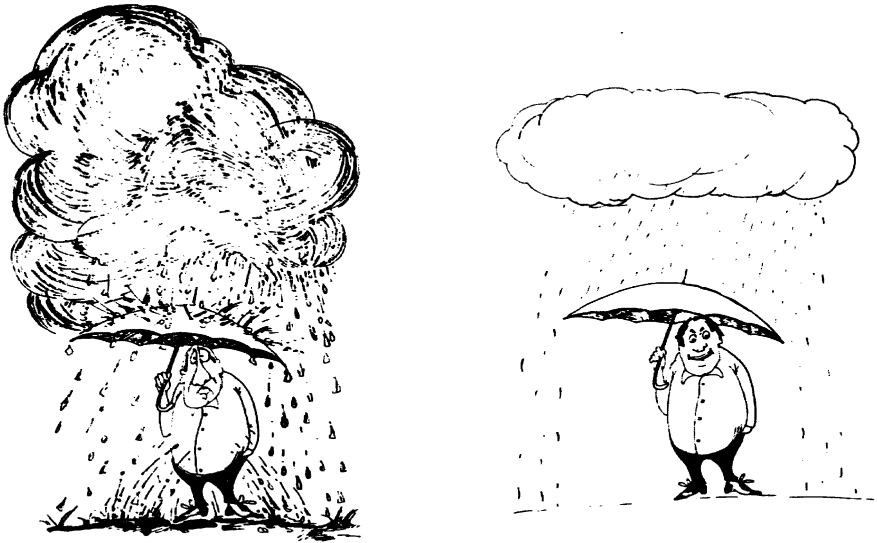

Figure 3. Contrasting rainfall events in monsoon climates. On the left is a tropical convective storm and on the right light continuous rain associated with a depression.

larger because the rate of precipitation would exceed the rate of infiltration. When the intensity is small, there would be very little plant movement (assuming a slow wind speed) so large quantities of water would collect on the vegetation resulting in efficient interception of water. Runoff would be small as virtually all the water reaching the soil surface would soak into the soil (providing it was not previously saturated).

The way that water is held on leaves is of paramount importance to the rate at which it evaporates. Let us consider a 10 mm^3 drop placed on each of three leaves (Fig. 4). The first leaf has a waxy cuticle and is water repellent so the drop assumes the shape of truncated oblate spheroid (Butler 1985) which maintains its shape as it evaporates. Its initial exposed surface area is 18 mm^2. The second leaf is slightly more wettable since water adheres to its surface, but the contact angle between water and the leaf surface is high, say 90^o. This drop has a similar initial exposed surface area (18 mm^2) but its shape changes as it evaporates. The base diameter remains the same as its height is reduced until it is a wet disc on the leaf (Barr and Gillespie 1987). The third leaf wets readily, and the water spreads out until it reaches a film of uniform thickness (say 0.1 mm). The exposed surface area would then be 100 mm^2, about five times that for the first leaf. In the same environment therefore we would expect the wettable leaf to dry about 5 times more quickly than the non-wettable one.

An example of this effect can be seen in Figure 5 where observed wetness on leaves of field bean and pea are compared

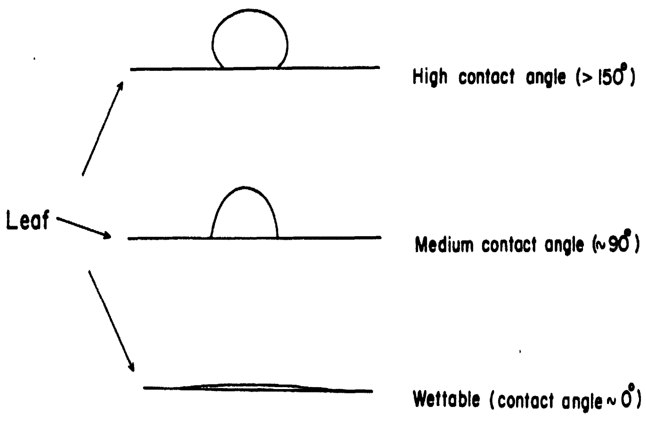

Figure 4. The degree of wettability of leaf cuticles affects the way water is held on the surface. The surface of the upper leaf is hydrophobic; the middle leaf is partly wetted but it holds discrete drops; the lower leaf is wettable and water spreads over the surface.

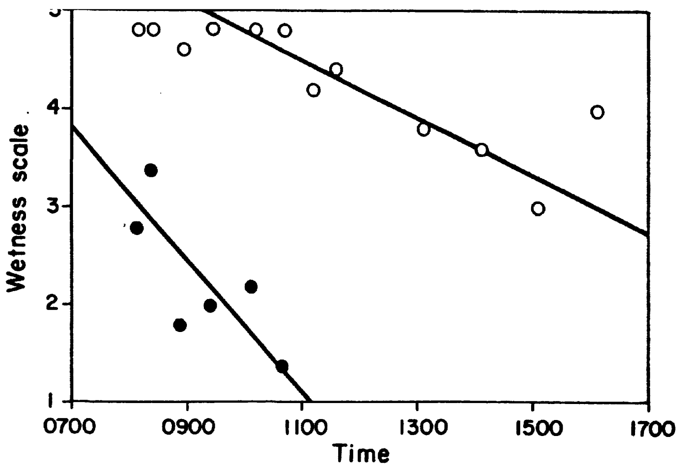

Figure 5. Leaf wetness assessments on adjacent crops in overcast conditions. The solid circles refer to field beans (wettable leaves) and open circles are for peas (discrete drops). The data are taken from Ward (1988).

(Ward 1988). The crops were grown in adjacent plots at Long Ashton Research Station, U.K. and the degree of wetness after rain recorded using a scale of 1 (dry) to 5 (saturated), taking the mean score for 5 leaves in each crop. The conditions were overcast and the beans (with wettable leaves) were dry by 1100 h whereas the peas (with discrete drops on the leaves) were still wet at 1700 h and probably did not dry until the next morning. Similar differences have been observed between pearl millet (with wettable leaves) and groundnut (with discrete drops) at ICRISAT Centre, Patancheru, A.P., India in overcast conditions.

If we now compare the two rainfall events (Fig. 2) for the same crop with non-wettable leaves, we find the following situations. With large intensity most of the water is shaken from the leaf surface, so at the end of the shower there remains only a few small drops (equivalent to say , 0.1 mm depth) which dry quickly. With small intensity rain the number of drops which adhere to the leaf in large because there is no leaf movement. In this situation it is feasible for the leaf to hold the equivalent of about 1 mm depth of water which would take at least 10 times as long to dry as in the first example.

The persistence of rain water on leaves is largely dependant on the nature of the leaf surface, and this complex situation is difficult to mimic with leaf wetness sensors. Wetness duration on sensors after rain often differs substantially from the duration on leaves of crops (Huband and Butler 1984). For dew the situation is quite different and much more satisfactory results are likely to be obtained from leaf wetness sensors. The correct response of sensors to dew depends on their siting which should be at the top of the crop canopy to indicate wetness on the upper leaves.

In summary, the estimation on wetness duration after rain is complicated by the nature of leaf surfaces and the way that water is held on the surface. The amount of water held on leaves dominates leaf wetness duration and is affected by the interception efficiency and leaf water holding capacity. These values are highly variable, depending on crop species and cultivar, leaf age, as well as rainfall intensity and wind speed. Current designs of leaf wetness sensors cannot realistically imitate all these variables, and progress towards producing good estimates of leaf wetness duration may result from modelling interception and evaporation.

References

Barr, A. and Gillespie, T.J. 1987. Maximum wetness duration for water drops on leaves in the field. Agricultural and Forest Meteorology 41:267-274.

Butler, D.R. 1980. Dew and Thermal Lag: measurements and an estimate of wetness duration on cocoa pods. Quarterly Journal of the Royal Meteorology Society 106:539-550.

Butler, D.R. 1985. The energy balance of water drops on a leaf surface. Boundary-layer Meteorology. 32:337-349.

Eyal, Z., Brown, J.F., Krupinsky, J.M. and Scharen, A.L. 1977. The effect of postinoculation periods of leaf wetness on the response of wheat cultivars to infection by Septoria nodorum. Phytopathology. 67:874-878.

Guzman, O. and Gomez, L. 1987. Permanence of free water on coffee leaves. Experimental Agriculture. 23:213-220.

Huband, N.D.S. and Butler, D.R. 1984. A comparison of wetness sensors for use with computer or microprocessor systems designed for disease forecasting. British Crop Protection Conference Proceedings 7A-6:633-638.

Mandal, G.S. 1988. Synoptic and local forecasting of climatic events. (These Proceedings).

Payen, D. 1988. Epidemic development in relation to meteorological factors (damage threshold, population dynamics). (These Proceedings).

Rudgard, S.A. and Butler, D.R. 1987. Witches' broom disease on cocoa in Rondonia, Brazil: pod infection in relation to pod susceptibility, wetness, inoculum and phytosanitation.

Ward, S.E. 1988. Wetness monitoring in crops. M.Sc. Thesis, Bristol University, U.K. 142 pp.