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(US Department of Commerce, NOAA, Auburn University, USA)

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REPORT ON THE MEASUREMENT OF LEAF WETNESS

1. INTRODUCTION

The measurement of leaf wetness has been a subject of study throughout history. Leaf wetness is a significant parameter for agriculture since it plays an important role with plant diseases, insect activity, the harvesting and curing of crops, and in the moisture balance of arid and semi-arid regions of the world. Several papers can be found in the literature (1,2,3) which provide a good general overview of dew and leaf wetness. Numerous instruments have been developed over the years to attempt to quantify leaf wetness. Various computer simulation models have also been devised to supplement or replace instrument readings. This report will briefly attempt to document some of the more recent technologies for monitoring leaf wetness and report on simulation models.

A detailed analysis of every instrument found in the literature will not be presented. Only brief comments will be provided where appropriate. Excellent summaries of various leaf wetness instruments have been previously compiled (4,5,6,7,8). Significant technological advances in recent years now make many leaf wetness instruments obsolete.

References cited in this report will be listed by number. The references are grouped according to the general class of instrumentation, ie. electronic, for the convenience of the user. This report is largely based on a computerized literature search and resulted in hundreds of references. To avoid duplication, some references on similar devices have not been included.

2. MONITORING LEAF WETNESS

Leaf wetness is defined as liquid moisture on leaves or other exposed surfaces. The source of the moisture can be from dew, fog, precipitation, and to a lesser extent from guttation. Most efforts have focused on detecting the presence of moisture which leads to a determination of the duration of wetting. Additional information such as the relative intensity of wetting (ie. light, moderate, or heavy) is also desirable. It is also important to be able to determine the source of the leaf wetness.

2.1 Instrumentation for Monitoring Leaf Wetness

A critical question that must be addressed is whether the instrumentation is to be used for operational measurements or for research work. Operational agricultural weather monitoring networks are usually comprehensive, with leaf wetness one of many environmental parameters being measured. The following characteristics are desired for any instrumentation, including leaf wetness, when used in an operational network:

a. simple design- few if any moving parts

b. rugged- capable of being constantly exposed to the weather

c. low routine maintenance- can be left unattended for long periods

d. easy to interface to electronic recorders (data loggers)

e. commercially available (if possible)

Instrumentation used in research applications is often more complicated and can require significant labor to keep in operation. The cost of instrumentation intended for research applications can be prohibitively expensive.

Leaf wetness instrumentation can be categorized into three groups. These groups are static devices, mechanical devices, and electronic devices.

2.2 Static Leaf Wetness Instruments

Instruments that have no mechanical or electronic parts are categorized as static devices. These devices are typically very rudimentary and are of minimal cost. However, they provide little useful information other than an indication of wet or dry condition. Detailed information such as the time wetting began or ended is not practical with most of these methods. These instruments are best when used to monitor dew and are ineffective for other forms of leaf wetness.

2.2.1 Duvdevani Dew Gauge

The Duvdevani instrument consists of exposing a standardized painted block of wood measuring 32 X 5 X 2.5 cm at sunset and observing it at sunrise. Based on a set of photographs, a relative dew scale number is assigned (11,12). This instrument has been documented (17) to have a poor correlation with dew duration in various crops. The requirement to expose the block of wood at sunset and observe it at sunrise is a very severe limitation.

2.2.2 Collection Funnels

Several devices (13,14,15,16) require the user to expose some surface on which dew forms and then collect the liquid into a measuring device. This only gives information on the volume of liquid (of questionable value) and provides no information on dewfall and dryoff times. These devices are useless for precipitation events.

2.2.3 *Absorption of Liquid*

The use of filter paper to absorb dew and other moisture from leaves and other surfaces has been proposed (9). This technique provides some information on dew amount but nothing about when dew began or if other wetting sources are included. Obviously, this method can only be used when there is liquid present on the leaves or other surfaces.

2.2.4 *Special Lysimiters*

While a lysimiter does obviously have mechanical parts, it is static in the sense that it can not be picked up and moved from one location to another. A lysimeter was used (10) in an attempt to measure the rate of dew deposition on a natural surface. The lysimiter is not an inexpensive device and requires considerable resources to operate and maintain. The lysimeter can not be used in precipitation events.

2.3 Mechanical Leaf Wetness Instruments

Numerous mechanical devices have been developed over the years for monitoring leaf wetness. Only a few have survived as commercially available instruments. Most of these devices attempt to detect wetting by weight or the change in length of a material. Another common device in the literature uses a special marking pen to determine when a detecting surface is wet. Various studies (4,5,6,7,8) have shown that these mechanical devices do not compare favorably with visual observations of leaf wetness.

2.3.1 *Weighing Type Instruments*

This type of instrument (18,19,22,23) is frequently known as a dew balance recorder. Various types of surfaces are used on which the moisture forms. The moisture is measured by weight. It is possible to determine the relative starting and ending times of dew and the intensity. This instrument is not useful for precipitation events.

2.3.2 *Change in Length Type Instrument*

One version (24) uses a water sensitive animal membrane which expands with the presence of liquid moisture. When the moisture evaporates, the membrane returns to its normal length. The membrane is connected to a mechanical recording device which indicates the presence or lack of moisture. The membrane also responds to relative humidity changes and does not allow operation during precipitation events. Other versions use a length of hemp material or paper (6).

2.3.3 Marking Pencil Instrument

The premise for this class of leaf wetness instrument is that certain kinds of marking pencils will dissolve in water. Moisture forms on a rotating glass plate or other sensing surface while the marking pencil contacts the sensing surface (20,21,24,25) and leaves a mark on the sensing surface when there is liquid moisture present. This type of instrument can not be used in precipitation events and is subject to numerous failures.

2.4 Electronic Leaf Wetness Instruments

The electronic leaf wetness instrument has become the predominate system. Technological changes have brought the cost of electronic recording devices such as data loggers to a point where a comprehensive agricultural weather monitoring system can be configured at a reasonable cost. The data is not only recorded but can be processed by the same system and produce a complete analysis. Leaf wetness is often measured as part of plant disease monitoring program, crop curing advisory program, or other activity in which temperature, wind, and other weather parameters are also being measured. The electronic leaf wetness instrument can be easily integrated into the data collection system. The data systems available today can be operated in remote areas using solar panels and batteries and can electronically record large amounts of data unattended. Interrogation of the data can be done by telephone, radio, or satellite.

There are four primary types of electronic sensing systems. One uses a special sensor to detect wetness. Another type uses clips which attach to the leaf or plant part. The third type places a wire grid over leaves or other material. The final type utilizes an artificial leaf on which wetness is detected.

2.4.1 Electronic Wetting Sensors

The sensors used in this method (33,37) are now of antiquated design but did provide the basis for later work which resulted in the development of the leaf clip and artificial leaf sensors.

2.4.2 Microclip Electrode Sensors

Microclip electrodes are attached to leaves (32,38). When moisture on the leaf bridges the electrodes, a change in voltage or resistance is recorded. The change is relative to the intensity of the wetting on the surface. With proper calibration using visual observations of heavy wetting, it is possible to obtain relative intensity values. These electrode sensors are not always sensitive to light amounts of dew. The microclips ultimately cause physical changes to the leaves.

2.4.3 *Wire Grid Sensors*

Similar to the microclip approach, a wire grid over a leaf has been used (35,36) to detect leaf wetness. The requirement that the grid be placed on a leaf is a serious limitation.

2.4.4 *Artificial Leaf Sensors*

Most leaf wetting instruments now in use are of the artificial leaf variety. Nearly all are based on a small printed circuit grid (5.8 X 7.8 cm) which is coated with different kinds of paint (27,28,29,30,31,34). The resulting sensor has about the same radiative characteristics as leaves. Thus, the sensor exhibits similar responses to dew formation and dryoff. Also, the sensor responds to precipitation and fog. It is easy to determine the source of wetting, the starting and ending times, and the relative intensity. The sensors can be exposed under a variety of conditions. Typically the sensors are openingly exposed or are placed within a field crop or even within the canopy of a tree. When sensors are connected in parallel, the output is an integrated reading for the entire environment in which the sensors are exposed. It is therefore possible to establish a standard exposure for leaf wetness monitoring. The artificial leaf wetting grids are commercially available. However, the grids must be painted by the user and interfaced to data loggers or other electronic recorders.

3. SUMMARY OF LEAF WETTING INSTRUMENTATION

There is now little if any use of the static leaf wetness instruments. Only a few of the mechanical devices (mainly the weighing type) are currently commercially available. Most leaf wetness monitoring systems are now based on the electronic device, primarily the artificial leaf design.

4. LEAF WETNESS SIMULATION MODELS

Various leaf wetting simulation models have been proposed (39-50). Some use an energy balance approach while others use simple correlation models. The basic problem with most of these approaches is that there is no recognized standard method of making actual leaf wetness measurements. Without a recognized standard, there can not be any credible verification of a simulation model. Many of the simulation models require detailed micrometeorological measurements which are not generally available.

5. RECOMMENDED STANDARD LEAF WETNESS INSTRUMENT

The electronic artificial leaf wetting sensor when integrated into a data logging system is the most powerful means of observing leaf wetness. This type of sensor allows the detailed recording of leaf wetness. The time of each wetting episode can be determined as well as the source of the wetting. Also, the relative intensity of wetting can be measured. This method meets all of the criteria outlined in section 2.1.

Much of the research conducted to date indicates that the artificial leaf sensors described by Davis and Hughes (28,29) and by Gillespie and Kidd (30) compare very favorably with visual observations of leaf wetness in various crop canopies. Additional research is needed in the paints used on the sensors and in the method of application.

It is recommended that either of these sensors be exposed in a heavy foliaged broad-leafed evergreen shrub 10 to 150 cm in height and planted within an agricultural weather observation site. There should be at least five sensors wired in parallel with the sensors placed at various heights in and over the canopy of the bush to obtain different degrees of shading. Use of an evergreen bush is suggested so that a similar exposure can be implemented at any desired location. A properly pruned evergreen bush will allow data collection year round. The sensors can be placed on growing crops, however the exposure will change as the crop grows. Data on sensor height and crop height would need to be regularly recorded.

A data logger would be the best means of monitoring the leaf wetness sensors. If this is not possible, a power supply and other electronics would be required so that the data could be monitored on a strip chart recorder. The electronics would need to be locally fabricated since there are currently no commercial versions available.

6. REFERENCES

6.1 General References

1 Mukammal, E.I., K. M. King, and H. F. Cork, Dew Amounts and Measurements. Unpublished manuscript.

2 Muller, W., 1968: The Role and Measurement of Dew. Agroclimatological Methods. Proceedings of the Reading Symposium, UNESCO, 303-307.

3 Stone, E. C., 1963: The Ecological Importance of Dew. The Quarterly Review of Biology. 38, 328-341.

6.2 Instrument Comparisons

4 Lomas, J. and Y. Shashoua, 1970: The Performance of Three Types of Leaf-Wetness Recorders. Agric. Meteor., 7, 159-166.

5 Noffsinger, T. L., 1963: Survey of Techniques for Measuring Dew. 1963 International Symposium on Humidity and Moisture, American Soc. of Heating, Refrigerating, and Airconditioning Engineers, 28 pp.

6 Post, J. J., C. C. Allison, H. Burckhardt, and T. F. Preece, 1963: The Influence of Weather Conditions on the Occurrence of Apple Scab. World Meteorological Organization Technical Note No. 55, WMO- No. 140.TP.65, 15-41.

7 Shaw, R. H., 1955: Comparison of Two Types of Dew Duration Recorders. Scientific Report No. 2, Iowa State College Dept. of Agronomy, 18 pp.

8 Wallin, Jack R., 1963: Dew, Its Significance and Measurement in Phytopathology. Phytopathology, 53, 1210-1216.

6.3 <u>Static Instruments</u>

9 Angus, D. E., 1958: Measurements of Dew. Proc. Canberra Symposium, Arid Zone Research-XI, UNESCO, 301-303.

10 Craddock, J. M., 1951: An Apparatus for Measuring Dewfall. London Royal Meteorological Society, 6, 300-308.

11 Duvdevani, S., 1947: An Optical Method of Dew Estimation. Royal Meteorological Society, 73, 282-296.

12 Duvdevani, S., 1964: Dew in Israel and Its Effect on Plants. Soil Science, 98, 14-21.

13 Hungerford, Kenneth E., 1967: An Acetate Dew Gage. J. Appl. Meteor., 6, 936-940.

14 Pickering, William H., 1913: A Year's Record with a Dew Recorder at Mandeville, Jamaica. Royal Meteorological Society, 39, 326-327.

15 Potvin, A., 1949: A Simple Method of Dew Measurement. Forestry Chronicle, 25, 52-53.

16 Scott, D., 1962: An Instrument Measuring Dew Deposition. Ecology, 43, 341-342.

17 Shaw, R. H., 1954: Comparison of Dew Duration on Duvdevani Dew Gauges and Several Crop Covers. Iowa State Dept. of Agronomy Report, 40pp.

6.4 <u>Mechanical Instruments</u>

18 Jennings, E. G. and J. L. Monteith, 1954: A Sensitive Recording Dew-Balance. Quart. J. Roy. Meteor. Soc., 80, 222-226.

19 Lloyd, Merle G., 1961: The Contribution of Dew to the Summer Water Budget of Northern Idaho. Bulletin American Meteorological Society, 42, 572-580.

20 Lomas, J., 1965: Note on Dew-Duration Recorders Under Semi-Arid Conditions. Agric. Meteorol., 2, 351-359.

21 Melching, J. S., R. D. Shrum, and R. G. Emge, 1970: An Eight-Day Dew Recorder. Plant Disease Reporter, 54, 512-515.

22 Morris, L. G., 1959: A Recording Weighing Machine for the Measurement of Evapotranspiration and Dewfall. J. Agric. Engineering Res., 4, 161-173.

23 Skachkova, I. F. and M. V. Shvarts, 1959: Ob izmerenii rosy. Meteorologiya i Gidrologiya, 4, 55-58. Translated from Russian, Republished- Israel Program for Scientific Translations: 1963: On the Measurement of Dew. Meteorologiya i Gidrologiya, 5 pp.

24 Taylor, Carlton F., 1956: A Device for Recording the Duration of Dew Deposits. Plant Disease Reporter, 40, 1025-1028.

25 Theis, T. and L. Calpouzos 1957: A Seven-Day Instrument for Recording Periods of Rainfall and Dew. Phytopathology, 47, 746-747.

26 Wallin, J. R. and D. N. Polhemus, 1954: A Dew Recorder. Science, 119, 294-295.

6.5 Electronic Instruments

27 Barthakur, N. N., 1987: Leaf Surface Wetness Duration Measurements by Radiogauge and Electronic Techniques. Commun. in Soil Sci. Plant Anal., 18, 405-419.

28 Davis, D. R. and Jerrell E. Hughes, 1970: A New Approach to Recording the Wetting Parameter by the Use of Electrical Resistance Sensors. Plant Disease Reporter, 54, 474-479.

29 Davis, D. R., Jerrell E. Hughes and R. E. Jensen, 1975: Instrumentation and Methods for Monitoring the Wetting Parameter in the Southeast. Preprints, 12th Conference on Agriculture and Forest Meteorology (Tucson), AMS, Boston, 11-12.

30 Gillespie, T. J. and G. E. Kidd, 1978: Sensing Duration of Leaf Moisture Retention Using Electrical Impedance Grids. Can. J. Plant Sci., 58, 179-187.

31 McCoy, C. W., A. J. Hill, and G. E. Horanic, 1972: A Device for Measuring and Recording the Amount and Duration of Free Water on Vegetation in the Field. J. Econ. Ent., 65, 135-138.

32 Melching, Stanley J., 1974: A Portable Self-Contained System for the Continuous Electronic Recording of Moisture Conditions of the Surfaces of Living Plants. Agricultural Research Service, U.S. Dept. of Agriculture, ARS-NE-42, 13 pp.

33 Peck, Richard C., 1964: A Capacitance Type Dew Detector. Manuscript of the U.S. Weather Bureau, U.S. Dept. of Commerce, 13 pp.

34 Smith, C. A. and J. D. Gilpatrick, 1980: Geneva Leaf-Wetness Detector. Plant Disease., 64, 286-288.

35 Weiss, A. and D. L. Lukens, 1981: Electronic Circuit for Detecting Leaf Wetness and Comparison of Two Sensors. Plant Disease, 41-43.

36 Weiss, A., D. L. Lukens, and J. R. Steadman, 1988: A Sensor For the Direct Measurement of Leaf Wetness: Construction Techniques and Testing Under Controlled Conditions. Agric. For. Meteorol., 43< 241-249.

37 Winters, R. and C. G. Small, 1934: An Automatic Moisture-Recording Device. Phytopathology, 24, 284-288.

38 Woolford, M. W. and J. D. Smith, 1963: Recording Wetness on Ryegrass (Lolium) Leaves. N.Z. J. Ag. Res., 6, 578-584.

6.6 Simulation Models

39 Alderman, D. Dorus and Kenneth E. Bryan, 1967: Short Range Forecasting of Dryoff Time from Dew Block Dew Intensity. Weather Bureau Technical Memorandum SR-36, U.S. Dept. of Commerce, 8 pp.

40 Cimino, Nicholas P., 1976: An Aid to Agricultural Dew Forecasting. NOAA Technical Memorandum NWS SR-87, U.S. Dept. of Commerce, 9 pp.

41 Coakley, Stella Melugin, Micheal J. Crowe and Robert G. Emge, 1978: Forecasting Dew Duration at Pendleton, Oregon, Using Simple Weather Observations. J. Appl. Meteor., 17, 1482-1487.

42 Harker, K. S. 1991: AWSC Auburn Leaf Wetting Estimation Model, National Weather Service, Auburn, AL. Unpublished manuscript.

43 Hill, Jerry. Forecasting Dew. Agricultural Forecast Techniques #1., Unpublished Agricultural Forecast Guide., 4 pp.

44 Jacobs, A. F. G.,W. A. J. van Pul,and A. van Dijken, 1990: Similarity Moisture Dew Profiles within a Corn Canopy. J. Appl. Meteor., 29, 1300-1306.

45 Kerr, J. P. and M. F. Beardsell, 1975: Effect of Dew on Leaf Water Potentials and Crop Resistances in a Paspalum Pasture. Agronomy Journal, 67, 596-599.

46 Lomas, J. and Y. Shashoua, 1970: The Performance of Three Types of Leaf-Wetness Recorders. Agr. Meteorol., 7 159-166.

47 Neumann, J., 1956: Estimating the Amount of Dewfall. Archiv. fur Meteorologie, Geophysik und Bioklimatologie, 9, 197-203.

48 Pedro, M. J. and T. J. Gillespie, 1982: Estimating Dew Duration. I. Utilizing Micrometeorological Data. Agr. Meteorl., 25, 283-296.

49 Pedro, M. J. and T. J. Gillespie, 1982: Estimating Dew Duration. II. Utilizing Standard Weather Station Data. Agr. Meteorl., 25, 297-310.

50 Smith, Paul D., 1978: The Effect of Wind and Dew Point on Vegetative Wetting Duration. NOAA Technical Memorandum NWS SR-94, U.S. Dept. of Commerce, 6 pp.