THE CONCEPT OF LEAF WETNESS USED IN AGRO METEOROLOGY

Tor Håkon Sivertsen
The Norwegian Crop Research Institute
Fellesbygget Høgskoleveien 7 N-1432 Ås Norway
phone. 47 649493078 fax. 47 64949226
e-mail: tor.sivertsen@planteforsk.no

Abstract

The conceptual frame for the discussion is introduced. Then the phenomenon called leaf wetness is discussed in an informal manner, and a documentation system for measured parameters is introduced, bringing examples from the measurements made in the automated station network of agro meteorological stations belonging to the Norwegian Crop Research Institute. Two examples of documenting parameters in the leaf wetness part of a SVAT-model is given. Parameters characterizing leaf wetness as input to biological modelling of infection of fungal diseases in crops are discussed. In the end part of this report contribution the concept of leaf wetness found in literature and on the web are discussed and criticized by using the conceptual frame of the preceding paragraphs.

Key words: Agro meteorology; Leaf wetness; Meteorological parameters

INTRODUCTION

The conceptual frame and theoretical background of this report contribution is another contribution to COST 718 'Discussing scientific methods and the quality of meteorological data', (Sivertsen, 2002). In this paper the concept of a meteorological parameter is discussed and defined on a general basis. The phenomenon of leaf wetness is an example of a meteorological/ physical phenomenon that may be described by quantitative attributes called 'parameters'. Below documentation of several parameters describing the phenomenon of leaf wetness is discussed, parameters connected to measuring systems as well as parameters connected to models.

The starting point of the discussion is a description of the known physics of the phenomenon. Then the system for documenting parameters is introduced. Several examples from measurements of parameters in the automated system of agro meteorological stations belonging to the Norwegian Crop research Institute are given.

THE PHENOMENON CALLED LEAF WETNESS

The surfaces of the leaves of agricultural crop canopies as well as trees, herbs and bushes of natural vegetation get wet due to precipitation, dew and fog. The phenomenon is easily observed with the naked eye.

Sometimes the water on leaves consists of scattered drops and sometimes it covers the leaves as a film. In some situations water is dripping from the leaves and the canopy and ultimately hits the ground below. Liquid water also evaporates from the surfaces of the leaves.

The processes mentioned may be described quantitatively, and certain quantitative attributes, parameters, may be defined and measured and scientific hypotheses containing these parameters may then be tested.

One important reason for studying the phenomenon of leaf wetness systematically is the close connection between leaf wetness and the infection of fungal diseases on the leaves and flowers of many agricultural crops and horticultural trees and bushes. It is therefore of interest not only to study the phenomenon on the very small scale of one single leaf or one single fruit, but also the vertical distribution of the phenomenon in a canopy, and furthermore the occurrence of the phenomenon in an agricultural field or in a whole region with agricultural crop production are of interest.

On the very tiny scale the shape of the individual leaf and the surface tension of the leaf surface in contact with water is of importance. The density and surface area of the leaves and the vertical and horizontal distribution of the leaves of the crop canopy influence the phenomenon. All these different dependencies may be quantified on the scale of a field of agricultural crops or on the local or regional scale of agricultural production.

A DOCUMENTATION SYSTEM FOR MEASURED PARAMETERS

In the paper referred to above, (Sivertsen, 2002), a general documentation system for measured and calculated meteorological parameters is proposed. The measured parameters contains the following attributes:

Name of the parameter
Unit
Definition
Method(s) for measuring the parameter
Representativeness for certain phenomena (models)
Connection to measuring system

The attribute above called

‘Representativeness’ will link the actual measured parameter to the different models or phenomena, and this attribute together with the attribute ‘Method(s) for measuring the parameter’ tells us something about the temporal and spatial resolution of the parameter.

The Norwegian Crop Research Institute is running a network of automated meteorological stations placed in the main agricultural regions of Norway. In this network are measured five different parameters connected to the phenomenon of leaf wetness. Below these five different parameters will be described in the frame proposed by the documentation system mentioned above. The parameters are used in plant protection warning systems connected to apple scab and potato late blight, as well as research connected to these diseases.

On most of the automated stations the following parameter is measured:

Name of the parameter:
‘Leaf wetness duration, measured 2m above the ground’

Unit:
‘minutes per hour’

Definition:
‘BT (the short name of the parameter) is defined as the duration of wetness during an hour of an artificial leaf surface placed 2m above the ground. It is the outcome of a measuring system consisting of a recording sensor of electrical conductivity, placed 2m above the ground in an inclined position leaning northward. The sensor of recording is placed at an automated meteorological station. The site of the station consists in most cases of some flat vegetated area covered with grass during the growing season.

Method for measuring the parameter:
‘The sensors recording leaf wetness duration are all placed 2m above the ground at automated agro meteorological stations. The sensors are unshielded and placed in a northward leaning position of about 30 ^{o}.

The instrument used for recording this parameter is a ‘Model 237 leaf wetness sensor, version CSL/1,’from Campbell Scientific Inc. The instrument measures the electrical resistance of a water film of fluid water on an artificial leaf consisting of a circuit board with interlacing fingers of gold-plated copper. The dimension of the plate is 7.5cmx 6.5 cm, but the active part of the sensor has a little smaller dimension, 5.8cm x 5.4cm.

The sensor resistance varies from above 3.000.000 ohms when dry to around 1.000 ohms when wet. The sensor has a wet-dry transition that occurs between 50.000 and 200.000 ohms.

The resistance is recorded

once a minute. The outcome then is the number of recordings showing a wet surface per hour.

Representativeness for certain phenomena (models):
'In this case any model of interest must be tested or operationally used in order to find the representativeness for the phenomena described by the model using this parameter. This measuring system is used in actual plant protection warning systems in Norway, but the representativeness of the outcome of this measuring device connected to the plant protection systems is not systematically documented yet.'

Connection to measuring system:
'A system for measuring the parameter is the automated network of 52 agro meteorological stations in Norway, owned by the Norwegian Crop Research Institute.'

Two other parameters in this system for making measurements are connected to the same type of sensor. One is called 'Leaf wetness duration measured by an artificial leaf surface inside a fruit orchard' (short name BTf), and the recording sensor is placed on the branch of a fruit tree or it is placed on the top of a logger inside the orchard.

The other parameter is called 'Leaf wetness duration measured by an artificial leaf surface in a potato field' (shortname BTp), and the sensor is placed inside a potato canopy in a potato field close to a logger.

A fourth parameter is called 'Leaf weness duration measured by two artificial leaf surfaces' (shortname BTff), and two Model 237(CSL/1) leaf wetness sensors are used. One of the sensors is placed on the top of a logger, and the other is placed 10-30m from the logger inside an orchard or inside a crop canopy. If one of the artificial surfaces is wet, the parameter is said to be wet.

The fifth parameter of interest for recording leaf wetness has got the short name BTj. It has got the name:
'Leaf wetness duration measured by an artificial leaf placed inside a straw berry canopy'. The measuring equipment is a model 237F leaf wetness sensor from Campbell Scientific Inc.. It is placed on sticks mounted with a sharp angle to the ground about 30 m from a logger. The dimension of the sensor is 1,5 cm x 9 cm, but the physicl principle is the same as for the other sensors mentioned.

DOCUMENTING MODEL CALCULATION PARAMETERS

The liquid water part of a SVAT-model (Soil-Vegetation-Atmosphere-Transfer-model) of a field of cereals, (Sivertsen ,1991), will be described below. This SVAT-model consists of an atmospheric boundary layer 10m above the

canopy, the energy and water balance of the air just above and inside the canopy and the energy and water balance in the soil below the canopy to a depth of one meter. The time step of the part of the model above the soil surface is one hour.
This SVAT-model was tested in a cereal field of spring barley and a cereal field of spring wheat, both areas were 0.1 hectar, and placed very close to a well equipped agro meteorological automated station.

Liquid water enters the canopy model system as precipitation (liquid drops of water), by irrigation or by dew, liquid water condensing directly on the leaves of the cereal canopy or on the ground below. The sources of water vapour in the air are the stomatas of the canopy, the ground as a porous system, and liquid water on the leaves and stems of the small corn.

In the five layers model of the canopy and the ground surface a liquid water balance budget for each layer is constructed.

The amount of liquid water entering the layer i, is called NbI_i. The amount of liquid water escaping from layer i to the layer (i+1) below, we call NbN_i. We then have got the following equation:

$$NbI_{i+1} = NbN_i$$

The unit of the parameters above are ms^{-1},or (m^3 / m^2) $second^{-1}$. The leaf area index of each layer of the canopy is known.

The upper layer of the canopy is given by the index i=1, and the surface of the ground is given by the index i=5.

The amount of liquid water on the leaves, stems and flowers in each layer is given by the parameter lw_i, the index runs from 1 to 5.

This parameter have the unit m or (m^3 / m^2). The upper limit of the possible amount of intercepted liquid water in each layer is denoted by the parameter Lw_i. The amount of liquid water vapourized from the layer is denoted by E^w .The unit of this parameter is m s^{-1} or $(m^3 / m^2)s^{-1}$.

For each layer of leaves etc. there is defined a liquid water balance budget of the following type:

$$NbN_i \cdot \Delta t = NbI_i \cdot \Delta t-((lw_i(t+ \Delta t) - lw_i(t)) - E^w{}_i \cdot \Delta t$$

This equation is defined for a time step Δt. lw_i never can be greater than Lw_i , which by Thomson (1981) is given by

$$Lw_i = xf_i$$

x is 0.05-0.10 mm and f_i is the LAI or leaf area index of the layer i. According to Thomson (1981) a leaf area layer of small corn will intercept 40 % of the incoming precipitation until half the interception capacity is reached and then intercept 15% of the precipitation until maximum interception capacity Lw_i is reached. Thomson (1981) refers to (Couturier and Ripley ,1973). In this paper the interception capacity for mixed prairie grass is discussed, and the interception processes mentioned above is derived as a natural growth function. Interception storage capacities are different for different species, (Rutter,1975).

In the testing procedures of Sivertsen (1991) a special way of measuring the LAI of each defined layer is used. This procedure is extremely time consuming and is impossible to use in operational situations. The sensibility of the model on LAI is not very thoroughly discussed by Sivertsen (1991).

For the soil surface the parameter NbI_5 is known from the processes in the first leaf layer above, and the following equation is used:

$$NbN_5 \cdot \Delta t = NbI_5 \cdot \Delta t - E^w{}_5 \cdot \Delta t$$

It is then possible to calculate the flux of liquid water into the soil by this equation or the net evaporation of water from the soil. The model does not include the process of runoff of water.

The concept of 'representativeness' of parameters, measured parameters or parameters derived from model calculation of certain phenomena, is discussed by Sivertsen (2002) (in the paper/ report mentioned above). The representativeness of a parameter in model is derived and defined through testing and operational use of the model, or testing of a minor part of the model. The definition of a parameter usually also tell us something about the representativeness of the parameter. In order to get some information connected to representativeness of a parameter used operationally, the operational results must be systematically analysed. Looking at an actual model and the actual phenomenon of representativeness for the parameter, it is of interest to take a look at two parameters, ' leaf wetness in a horizontal layer of a homogenous cereal canopy', and ' leaf wetness duration in a horizontal layer of a cereal canopy'. The first parameter is described above in the system of equations connected to processes involving liquid water in the canopy, and it is denoted lw_i by the short name used.
The model is a five layers model of a certain cereal canopy in the field very close to an automated agro meteorological station to get relevant input values of meteorological parameters to perform calculations in the model.

Examples of documenting two model parameters describing leaf wetness follow. The short names of these parameters are lw_2 and t_2.

Name of the parameter: The amount of liquid water in the second layer of a cereal canopy model of five layers

Unit: m (m^3 / m^2)

Definition: lw_2 is the volumetric amount of liquid water per m^2 leaf area in the second canopy layer (defined by height above the soil surface and leaf area index) of this model of a five horizontal layer canopy model of cereals.
The amount of liquid water is only considered to exist as a water film, not as separated drops of water on the plant material.

Representativeness of the phenomena of the model considered: The physical processes connected to liquid water on plant material are described by Sivertsen (1991), and these processes are just a minor part of the SVAT-model. This model is tested in a field of spring wheat and a field of spring barley through the growing seasons 1989 and 1990. The hourly meteorological input data to the model comes from an agro meteorological station less than 100m from the small experimental fields. No measured leaf wetness parameter is an input part to this model. The testing of the liquid water part in the field is performed by comparing the duration of leaf wetness in the model to two separate masts with 'Model 237 leaf wetness sensors, version CSL/1,'from Campbell Scientific Inc., (Sivertsen ,1991). The parameter lw_2 is considered relatively representative to phenomena on this micro meteorological time and spatial scale of a field of small grain.

Representativeness for certain phenomena in other models: 'Phenomena of interest in this connection would be extending the model from the micro meteorological situation to local and regional phenomena of this type. This can be performed through operational use of the model and systematic discussion of operational model results. This model has never been used operationally.'

Connection to modelling system: The SVAT model considered is described by Sivertsen, 1991.

The other parameter to be presented in the documentation system has the short name t_2 in this report.

Name of the parameter: The duration of leaf wetness in the second layer of a cereal canopy model of five layers

Unit: second

Definition: t_2 is duration in an hour of the volumetric amount of liquid water per m^2 leaf area in the second canopy layer (defined by height above the soil surface and leaf area index) of this model of a five horizontal layer canopy model of cereals.
The amount of liquid water is only considered to exist as a water film, not as separated drops of water on the plant material.

The other attributes for this parameter are identical to the attributes of the parameter lw_2.

LEAF WETNESS USED AS INPUT TO BIOLOGICAL MODELS

In several agro meteorological models some sort of parameter characterizing leaf wetness duration is used as an input to the models (especially biological models describing the infection of fungus in fruit orchards or in agricultural crops, see Stensvand et. al. 1997). The input of leaf wetness duration to models must be derived through some process of measurement or some process of calculation.

In order to use such models, the models ought to have been tested in some sensible way. This means there must have been some way of deriving and defining such parameters in a testing system, in a laboratory or in a field.
Examples of the derivation of parameters characterizing leaf wetness duration either by measurement or by calculation are discussed above. Such parameters derived from measurements or from calculation procedures of a micro meteorological model may be used as input to biological models in operational use. By systematically analysing the results of such operational use, the representativeness of the parameters may be derived for the different biological models.

THE CONCEPT OF LEAF WETNESS DISCUSSED IN THE LITERATURE

The web-page 'http://www.nysaes.cornell.edu/swd/' is called 'The Leaf Wetness Duration Home Page'. The 5 first paragraphs of the content of this web-page is organised in the following way:

'1. Surface wetness duration (Surface wetness versus leaf wetness, definitions, Frequency distribution, plant pathology, pollution)
2. Measuring leaf wetness with electronic sensors
3. A measurement standard for surface wetness duration
4. Simulation of leaf wetness
5. Alternatives to the use of sensors'

This web page contains much of the same material as the discussion of this report. It is my opinion that much of the discussion could be clarified by documenting each parameter characterizing leaf wetness or surface wetness in the way proposed above. Constructing a measurement standard on agro meteorological stations, probably would make it easier to exchange data sets and use exchanged data sets containing leaf wetness measurements, but it must then be possible and useful to apply this standard as an input to different models of interest. This demands a testing procedure for each model, or a system for analysing the results of using such a standard operationally.

Another work of interest is connected to COST ACTION 718 and presented at the EGS-congress in Nice

2002 (Dietrich et. al, 2002):
"Using remotely sensed data for leaf wetness duration measurement":

"The idea is to develop and to validate a physical model for leaf wetness duration (LWD) measurement working in topographical way, taking advantage from precipitation fields supplied by polarimetric radars (and/ or microwave satellites in a subsequent phase), and from network measurements of ground based weather stations (and/or satellite measurements in a subsequent phase)."

"In order to achieve the objective, the combined job of three different research groups is organised: One group is looking at the remote sensing measurements of precipitation by radar. Another group is looking at the model work, the physical models of simulation of leaf wetness. The third group is looking at the measurements of other variables, and tries to validate LWD model outputs by means of LW sensor measurements.

The reason for the energy invested is the need for this parameter as input to models of the growth of fungal diseases in grape wine yards.

The conclusions at this early stage:

- A polarimetric radar is a good source of rain-induced leaf wetness measurements.
- Radar is not enough to describe LED fields because large part of wetness is due to evaporatranaspiration.
- The formation of dew is to be solved.
- LW models cannot be used as black boxes.
- Net radiation measurements could improve the application for cloudiness conditions."

This comprehensive project is an example of investing much energy in solving a real problem to be adequately used in operational manner later on. Then we must invoke the hypothetico-deductive principle, and actually use it in the process of testing as well as in the process of operational use, both for LW models as well as the biological models using LWD as input. One step would be to look very thoroughly at the model of fungus infection (in this case the model PERO), to see how this model is tested, and especially see how the input parameters characterizing leaf wetness duration are characterized and defined for different spatial scales. On which scales is this model actually tested?

The next step would be to look closer at the representativeness and temporal and spatial scales of the different parameters characterizing leaf wetness as well as other parameters (precipitation etc.) by using some sort of documentation system like that proposed above.

By systematically taking these

steps it should also be possible to invoke analysis and corrections according to the hypothetico-deductive principle also in the process of operational use of such a system.

One concept proposed in this contribution is the concept of ‘objective sensor of leaf wetness duration measurement’. There exist no objective measurement of this phenomenon, but the parameters actually used for describing the phenomenon ought to be documented on each scale of interest, the single leaf, the canopy, the field or orchard, and the agricultural region.

ACKNOWLEDGES

The author wants to thank Yngve Lien for copy reading and several useful discussions, and he also will thank Arne Stensvand for discussions at one occasion.

REFERENCES

Couturier, D. E. and Ripley, E. A., 1973, Rainfall interception in mixed grass prairie, Canadian Journal of Plant Science, 53, 659-663

Dietrich, S, Alilla, R., Cicogna, A., Fabbo, R., Gani, M., Giovanardi, R., Orlandini, S., Sandra, M., Severini, M., and Maracchi, G., 2002, Using remotely sensed data for leaf wetness duration measurements, EGS 2002: XXVII GENERAL ASSEMBLY, NICE FRANCE 21-26 APRIL 2002

Rutter, A. J., 1975, The hydrological cycle in vegetation, in 'Vegetation and the Atmosphere', Volume 1, ed. Monteith, J. L., Academic Press

Sivertsen, T.H. ,1991, Konstruksjon og testing av en fysisk matematisk mikrometeorologisk modell for en kornbestand, Institutt for tekniske fag, Norges landbrukshøgskole , Ås, Norway, 157 pp, In Norwegian

Sivertsen, T.H. ,2002, Discussing scientific methods and the quality of meteorological data, COST 718, 19 p

Stensvand, A., Gadoury, D. M., Amundsen, T., Semb, L., and Seem, R.C., Ascopspore and Infection of Apple Leaves by Conidia and Ascopspores of *Ventura inaequalis* at Low Temperatures, 1997, Phytopathology 87 No. 10.

Thompson, N., 1981, The Duration of Leaf Wetness, The meteorological magazine No. 1302, Vol. 110, Meteorological Office

The Leaf Wetness Duration Home page, 'http://www.nysaes.cornell.edu/swd/' This web site contains 116 references.