

Estimating potato crop wetness duration from agrometeorological data

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सार — आलू की खेती के लिए इसके आरम्भ, समाप्ति तथा कुल आर्द्रता अवधि (डब्ल्यू डी) का अनुकरण करने के लिए जीव भौतिकीय मॉडल तथा सापेक्ष आर्द्रता (आर एच) की विभिन्न सीमाओं को मान्य ठहराने के लिए इसकी फसल के प्रति घंटे के मौसम वैज्ञानिक प्रेक्षणों का उपयोग किया गया। मॉडल से एक घंटे से कम की माध्य सम्पूर्ण त्रुटि के साथ बहु आर्द्र और शुष्क तथा लम्बे समय तक नमी की परिस्थितियों का अनुकरण करने की क्षमता का पता चला। जब केवल सापेक्ष आर्द्रता का उपयोग किया गया तब मापा हुआ और आकलित आरम्भ तथा कुल आर्द्रता अवधि के बीच विचलन अधिक सुस्पष्ट था। तथापि, भारत में आलू की खेती वाले क्षेत्रों की प्रबल कृषि जलवायविक परिस्थितियों में मौसम के कारण होने वाली बीमारियों की रोकथाम संबंधी परामर्श हेतु आर्द्रता अवधि का आकलन लगाने के लिए 80 प्रतिशत सापेक्ष आर्द्रता सीमा पर्याप्त हो सकती है।

ABSTRACT. Hourly meteorological observations over a potato crop field were used to validate a biophysical model and different thresholds of relative humidity (RH) to simulate the onset, cessation and total wetness duration (WD). The model showed the capability to simulate multiple wet and dry conditions as well as prolonged moist conditions with a mean absolute error of less than an hour. The deviation between measured and estimated onset and total WD was more pronounced when only RH was used. However, under the prevailing agroclimatic conditions of potato growing regions in India, 80% RH threshold may adequately be accurate to estimate WD for many weather-based disease management advisories.

Key words—Micro-climate, Energy balance, Wetness duration, Relative humidity, Plant protection, Potato crop.

1. Introduction

The micro-climate in an agricultural field influences the conditions favourable for pest and disease multiplication. Many plant diseases are affected by the duration of time for which leaves or other plant parts are wet (WMO 1988). Weather-based disease management schemes (Krause *et al.* 1975, Sutton *et al.* 1986, Madden *et al.* 1978) use ranges of wetness duration (WD) and temperature during that period to classify the weather as favourable or unfavourable. In order to provide crop specific advisory to Indian farmers (Rathore *et al.* 1996, Sanjeeva Rao *et al.* 1996) to maximise the efficacy of pesticides, estimates of WD are essential (Gillespie 1994, Gleason *et al.* 1995).

The wetness may be caused by dew, rainfall, fog, mist, guttation or sprinkler irrigation. Of the all dew is most important source of leaf wetness during winter months for

regularity in formation. Despite the importance of WD, real time data is not available because of difficulties in measurement of dew. Surface moisture often evaporates by the time routine morning observations are made. Therefore, information on WD is required to be inferred from observed weather data or from weather forecasts (Huber and Gillespie 1992, Wilks and Shen 1991). Hence, estimation of WD from agrometeorological data is a practical alternative to the application of artificial sensors in the field of pest and disease management.

A single-layer biophysical model to infer dew from micro meteorological data and leaf characteristics, based on energy balance and heat transfer theory was devised and adapted to different crops and regions (Pedro and Gillespie 1982; Gillespie and Barr 1984, Lhomme and Jimenez 1992, Scherm *et al.* 1995). The objectives of the present study are: (a) to validate the application of similar modelling principles

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TABLE 1
Comparison of observed meteorological conditions with the early onset of wetness by the sensor over potato crop differ by >2h from model (Mode 1) simulation

Julian day		Time (H)	T _{air} (°C)	RH (%)	Wind (m/s)	Radiation(W/m ²)	
						Net	Income
349	obs	16	22.2	52.4	3.3	106.4	239.5
	mod1	21	13.7	87.7	0.7	-41.7	0.6
350	obs	18	19.0	52.4	3.4	-58.2	8.6
	mod1	24	11.4	80.2	0.9	-53.0	0.6
351	obs	21	13.3	60.5	1.5	-52.3	0.6
	mod1	24	9.3	80.2	0.5	-49.0	0.6
353	obs	18	17.9	64.7	1.4	-43.5	6.1
	mod1	21	13.2	82.3	0.7	-45.5	0.6
358	obs	18	16.8	55.4	0.8	-55.1	5.4
	mod1	25	10.6	84.4	0.3	-32.1	0.6
13	obs	16	20.5	37.6	4.2	155.8	292.6
	mod1	22	12.0	84.8	0.7	-22.7	0.6
55	obs	17	24.1	63.3	1.9	102.3	235.0
	mod1	21	18.2	84.8	1.1	-32.8	0.6
59	obs	18	22.1	66.1	2.4	27.3	124.4
	mod1	22	15.4	88.6	1.1	-32.9	0.3

Obs: observation; mod1: model simulation with cloud information

after transporting to a new location and crop fields of potato, and (b) to test the accuracy and sensitivity of wetness estimations using only RH thresholds.

2. Materials and methods

2.1. Field measurements

Hourly weather data were obtained from a micro-meteorological tower and an additional short mast situated near the center of a 50m x 50m plot of potato crop (variety Kufri Bahar, susceptible to late blight), planted at Pantnagar (Lat. 29°N, Long. 79°30' E, Alt. 243.8m), India. The crop was planted on 10 November 1995 and harvested on 24 March 1996. Data recorded at the tower were: wind speed (Model A-100R pulse anemometer, Campbell Scientific) at 3.1m, incoming solar radiation and rainfall at 1 m. A flat plate electronic impedance grids (Campbell Scientific, UK) leaf wetness sensor was positioned at a height of 1m above the ground. The nearby crop mast held a temperature/humidity probe (Model HMP 35 AC, Campbell Scientific) just above the upper crop canopy, was moved upwards as the crop grew. All these observations were recorded every minute with CR-21X Micro-logger (Campbell Scientific, UK).

2.2. Biophysical model

The air-to-leaf temperature difference (dT) is one of the dominant factors which control the onset of dew formation and duration. In the absence of leaf temperature (T_l), the energy balance of an individual leaf can be solved for dT , as suggested by Kreith and Sellers (1975) and Norman (1982). Wind speeds near the crop top were derived from winds

measured at 3.1 m, using power law profile (Campbell, 1977). Stability was judged from wind speed and net radiation values. For periods when dew is forming or evaporating it is expected that only very small differences exist between vapour pressure in the crop and the surrounding environment. Assuming that the surface temperature of both sides of leaf are equal, temperature surrounding the canopy and T_l are relatively close to each other, an iteration procedure was repeated until dT changed by $< 0.1^\circ\text{C}$ between successive trails. The resulting dT value was taken as the true leaf air temperature difference.

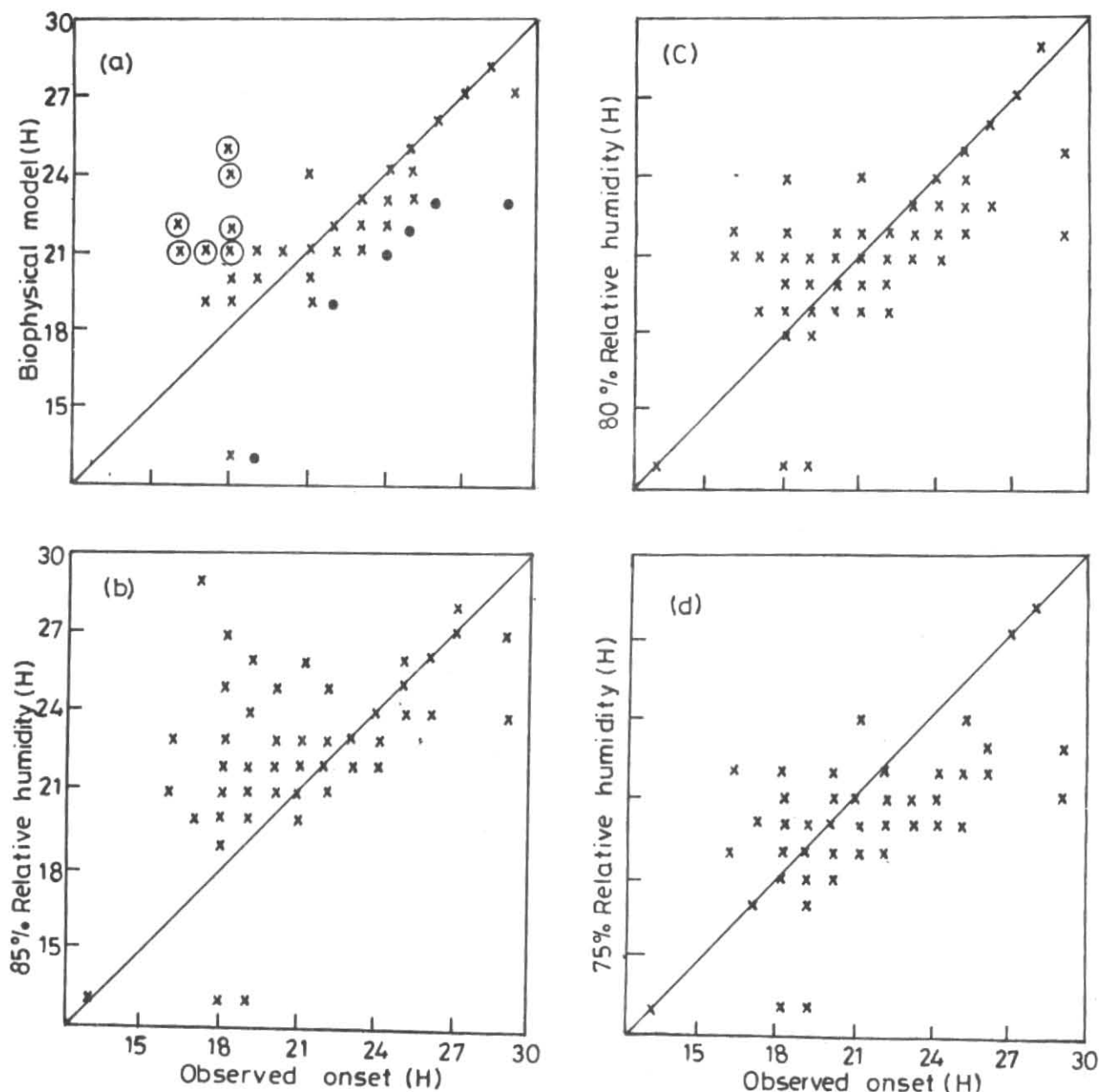
The latent heat flux (LE) is obtained as

$$LE = -(0.622/p) * 2hw (0.95e_{sl}-e)$$

where P is atmospheric pressure, e_{sl} is saturated vapour pressure at T_l , e is ambient vapour pressure and hw is the convective vapour transfer coefficient for flat objects (Campbell, 1977).

The model was operated in two modes. For mode 1, the sky was assumed to be free of any substantial cloud, except during times when rainfall was recorded. When rainfall was recorded, the sky emissivity was increased by a factor 1.2, which is a typical adjustment for overcast low clouds. In mode 2, the model was run with the factor of 1.2 continuously in place. Radiation data were used to identify dry but cloudy periods when mode 2 is more appropriate than mode 1.

Occurrence of $LE > 0$ signals the onset of wetness and accumulation of dew deposition. The model accumulates this dew during the night, then signals the end of the dew



Figs.1. (a-d) Relationship between observed and estimated time of onset of wetness over a potato crop field at Pantnagar. (a) Biophysical model simulation, (b) Relative humidity at 85% threshold, (c) Relative humidity at 80% threshold and (d) Relative humidity at 75% threshold

period when an equivalent amount of evaporation has occurred in the morning. When there is rainfall, it initiates or augments wetness and is added to positive *LE* reservoir up to a value of 0.4 mm, which was found to be the maximum rain interception for a potato leaf. The difference between wetness cessation and onset during 1201 h to 1200 h the next day was defined as WD for that day. The simulation of WD begun one week after planting to allow emergence. The crop heights used in the simulation were 10 cm shortly after emergence then increasing to 40 cm at harvest. In total, 119 days were included in the simulation.

2.3. Relative humidity threshold

The period of time that RH at the crop height remains above a threshold has been used as a surrogate for WD (Bourke, 1965). In the present study three thresholds, namely; 75%, 80% and 85% were validated against wetness measurements over a potato field.

3. Results and discussion

Rainfall is measured at many locations, but not the dew and wetness duration. Dew is the principal source of moisture, next to rainfall, to keep the crop canopies wet for

TABLE 2
Comparison of the time of model simulation with observation over potato crop

Julian day	obs (H)	mod 1 (H)	mod 2 (H)
344	24	21	24
348/9	02	23	01
18	19	13	19
19	18	13	13
24/25	05	23	03
45	22	19	22
54	07	21	Dry
62	22	19	21

obs: observation; mod 1: model simulation without cloud information; mod 2: time of model simulation with cloudy conditions.

sufficient time in this region. The process of dew denotes the latent heat flux towards the canopy and has bearing on its micro-climate. The conditions necessary for heavy dew are clear skies and high absolute humidity near the surface and some turbulent mixing to bring fresh moist air down to the crop surface.

During the potato crop growing period of 1995-96, 172.4 mm of rainfall was spread over 10 day period and its total duration was 63 hours. Dew amounting to 0.2 mm was recorded between 0100 h to 0900 h on 22 days. The most common times were 0500 h and 0600 h, each with four occurrences. The wetness sensor indicated that intermittent dry periods lasting more than one hour were encountered on 7 days. Only 8 days (Julian day nos. 321, 347, 12, 27, 38, 39, 54 and 72) were observed as either dry or about 3 h wet conditions.

3.1. Onset of wet period

The initiation of leaf wetness using the biophysical model in mode 1 is shown in Fig.1(a). The onset on 85% of the days are in good agreement (± 2 h). Of the 16 occasions differed by >2 h, there are 6 situations indicated as circles, where there was strong evidence that early onset by the wetness sensor giving a reading that was not representative of the underlying crop (Table 1). In some cases the sensor showed early initiation when RH was $<60\%$, and no rain was reported. In other cases the sensor showed late onset with a short dry period when RH was $>90\%$, solar radiation was weak, and sometimes rain was recently reported. On a further 8 of the 16 days [indicated by dark circles in Fig.1(a)], it could be inferred from radiation data that skies were overcast even though no rain was reported. This required that model be run in mode 2 which significantly improved its performance (Table 2). There were only 2 occasions during the simulation period where the onset was conclusively in error by >2 h. Thus, the model demonstrated a good deal of skill throughout the growing season including intermittent dry periods.

The mean absolute error (MAE), which is the difference between the time of observed and modelled wetting onset

was 1.07h. These results show that the model is quite skilful, recalling that the input data are at hourly intervals. During these simulations it became clear that initiation of modelled condensation at a leaf RH of 95% was most successful, suggesting the slightly hygroscopic substance (such as wind borne clay particles) were present on the leaves. Also, favourable wet conditions begin at mid-day on some days associated with the rainfall. In general, initiation of wetness in the region is at around 1900 h.

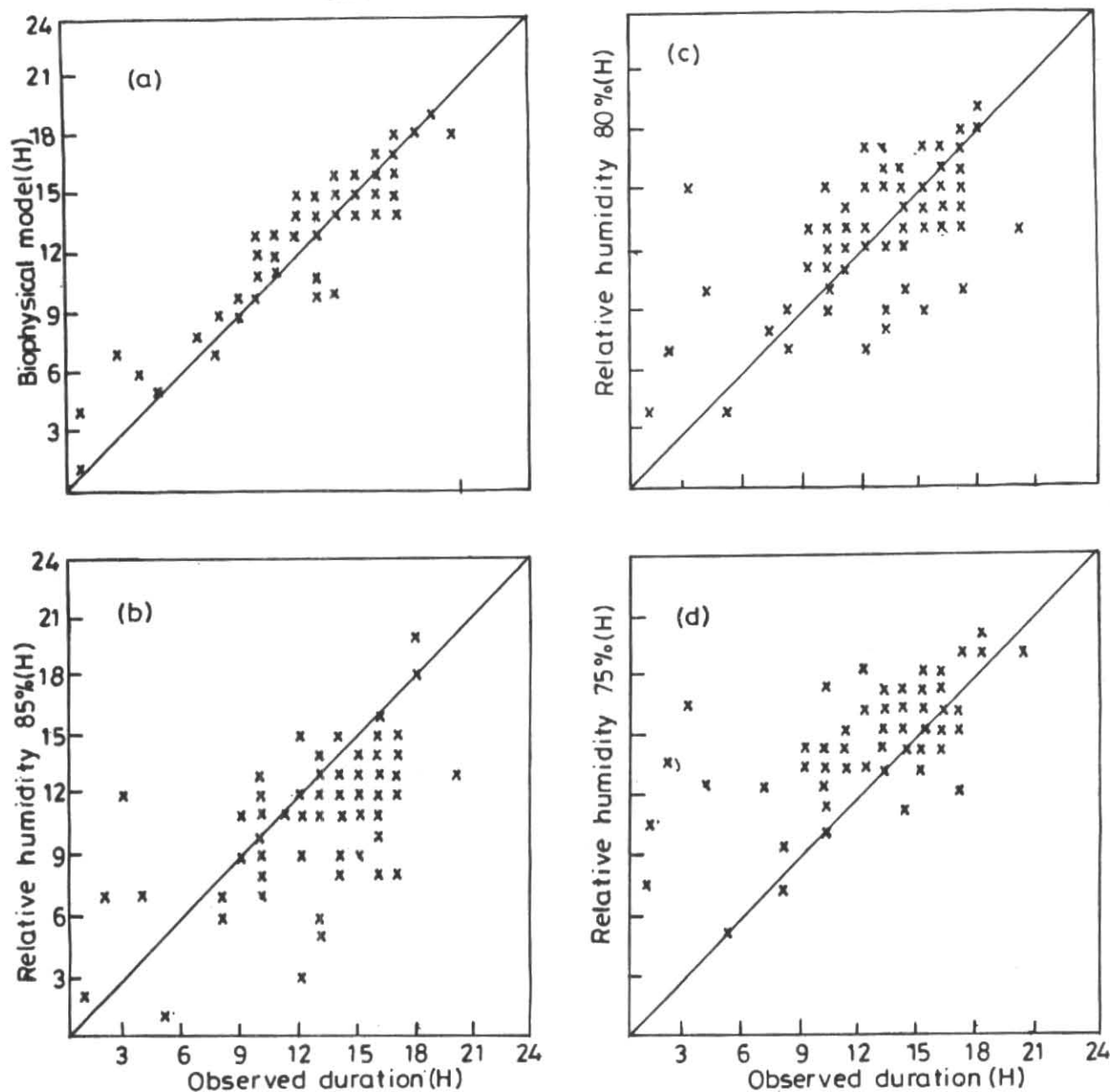
Figs.1(b-d) showed the relationship between the estimates of initiation of wet conditions in a day during the potato growing season at Pantnagar using RH thresholds of 85%, 80% and 75%, respectively. The 85% threshold leads to late onset of wetness. However, the dispersion shown in Figs.1(c & d) indicates reasonable estimates of onset of wetness could be obtained from RH thresholds of 75% or 80%.

3.2. Cessation of wetness

On only 2 days the biophysical model was exceeded 2 h of observed cessation. The MAE was 30 minutes. Thus cessation of moist weather conditions in a potato crop was more accurately simulated than onset. This is because the drying process is usually dominated by solar radiation which is capable of evaporating a range of intercepted rain or dew amounts within the same hour. On the other hand, onset of dew is a more complicated process where subtle changes in humidity, temperature, wind, cloud can interrupt or enhance the process (Scherm and Van Burggen, 1993; Wittich, 1995).

3.3. Total wetness duration

The wetness initiation and ending times can be combined to yield the duration of wetness, which is the variable of most interest. Fig.2(a) shows the measured and biophysical model simulated WD, which omits the 6 dubious points due to sensor problem and 7 points due to multiple wet and dry periods. Out of the 106 days estimated (emergence to harvest), 46 days are in close agreement, 35 days are with ± 1 h and 16 days are with an error of 2 h. The MAE of 0.9



Figs.2(a-d). Relationship between observed and estimated total wetness duration over a potato crop field at Pantnagar, (a) Biophysical model simulation, (b) Relative humidity at 85% threshold, (c) Relative humidity at 80% threshold, and (d) Relative humidity at 75% threshold

h and with only 8.5% of the days simulated wetness periods differing in duration by > 2 h from measured values. The correlation coefficient is 0.96. Therefore the degree of scatter shown in Fig.2(a), and in similar modelling in other parts of the world, does not prevent the simulated WD values from being very useful as a disease management tool (Schermer *et al.*, 1995).

A review of the present observational data suggest that the choice of 90% RH threshold would significantly underestimate WD. Figs.2(b-d) show the measured WD plotted against the duration of RH $\geq 85\%$, $\geq 80\%$ and $\geq 75\%$, respectively. The correlation coefficients are 0.77, 0.77 and 0.74, respectively for RH thresholds of 85%, 80% and 75%. The

scatter of points reveal that the best match to measured WD was obtained with the 80% RH criterion - 85% lead to underestimates of WD, while 75% lead to overestimates. Comparison of Figs.2(a-d) shows that the dispersion of points is greater when only RH is used to estimate wetness duration as compared to a biophysical model. This is to be expected since RH threshold approach ignores the additional influences of wind and sky conditions on condensation and evaporation.

Crop WD is highly sensitive to canopy level RH. Condensation of moisture at 95% RH indicates that local tuning is essential while transporting agrometeorological models developed elsewhere. These results also suggest that such a

simple model could form the basis of a wetness duration forecast system which would convert forecast variables from the available general circulation model, into estimates of expected wetness duration. This would provide an objective basis for issuing plant disease warnings or assurances that disease-favourable weather is not likely.

4. Conclusions

On the basis of the results discussed above, the following general conclusions may be drawn: (1) The initiation of wetness showed considerable variability when compared to cessation. In other words, condensation of moisture over sunlit potato leaves is more sensitive to the changes in micro-climate, in particular to relative humidity and cloud conditions; (2) The biophysical model showed the capability of simulating the leaf wetness duration to match the varying duration of less than 3 h to near 24 h per day prevailing in the agricultural fields. Very accurate estimates could be possible with more input information about the boundary conditions and short interval weather data; (3) Validation of agrometeorological models in estimating wetness conditions over a crop field are essential while transporting such models developed elsewhere for real time application in a new region, and (4) In order to estimate the microclimatic variability at the crop level in an agricultural field, very accurate forecast of relative humidity are necessary. After obtaining reasonable estimates of the crop environment, the decision support systems may provide accurate plant protection advisories.

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References

- Bourke, P.M.A., 1965, "The forecasting from weather data of potato blight and other plant diseases and pests", *WMO Tech. Note No. 10*.
- Campbell, G.S., 1977, "An Introduction to Environmental Biophysics", Springer-Verlag, N.Y., 159p.
- Gillespie, T.J., 1994, "Pest and disease relationships", In Handbook of Agricultural Meteorology, (ed) J.F. Griffiths, Oxford University Press, N.Y., 203-209.
- Gillespie, T.J. and Barr, A., 1984, "Adaptation of a dew estimation scheme to a new crop and site", *Agric. For. Meteorol.*, **31**, 289-295.
- Gleason, M.L., MacNab, A.A., Pitblado, R.E., Ricker, M.D., East, D.A. and Latin, R.X., 1995, "Disease-warning systems for processing tomatoes in eastern north America: Are we there yet?" *Plant Dis.*, **79**, 113-121.
- Huber, L. and Gillespie, T.J., 1992, "Modelling leaf wetness duration", *Ann. Rev. of Phytopath.*, **30**, 553-577.
- Krause, R.A., Massie, L.B. and Hyrer, A., 1975, "BLITECAST: A computerised forecast of potato blight", *Plant Dis. Rep.*, **59**, 95-98.
- Kreith, F. and Sellers, W.D., 1975, "General principles of natural evaporation". In: Heat and Mass Transfer in the Biosphere. I. Transfer processes in Plant Environment., (eds.) D.A. de Vries and N.H. Afgan, Scripta Book Co., Washington, 207-227.
- Lhomme, J.P. and Jimenez, O.P., 1992, "Estimating dew duration on banana and plantain leaves from standard meteorological observations", *Agric. For. Meteorol.*, **62**, 263-274.
- Madden, L., Pennypacker, S.P. and MacNab, A.A., 1978, "FAST: A forecast system for *Alternaria solani* on tomatoes", *Phytopathology*, **68**, 1354-1358.
- Norman, J.M., 1982, "Simulation of microclimates", In: Biometeorology in Integrated Pest Management, (eds.) J.L. Hatfield and I.J. Thomson, Academic Press, N.Y., 491p.
- Pedro, M.J., Jr. and Gillespie, T.J., 1982, "Estimating dew duration, I. Utilising micrometeorological data", *Agric. Meteorol.*, **25**, 283-296.
- Rathore, L.S., Sanjeeva Rao, P., Saseendran, S.A., Mendiratta, N., Singh, K.K., Gupta, A. and Bahadur, J., 1996, "Agromet advisory services for Himalayan region", In: Farming system in the Himalayas, Ministry of Agriculture, Department of Agriculture Cooperation, New Delhi, 65-72.
- Sanjeeva Rao, P., Kumar, A., Saseendran, S.A., Singh, K.K., Maini, P., Mendiratta, N., Rathore, L.S. and Bahadur, J., 1996, "Development of weather based agro advisory services from NCMRWF", In: Advances in Tropical Meteorology: Meteorology and National Development, (eds) R.K. Datta, Concept publishers, New Delhi, 298-306.
- Scherin, H. and Van Bruggen, A.H.C., 1993, "Sensitivity of simulated dew duration to meteorological variations in different climatic regions of California", *Agric. For. Meteorol.*, **66**, 229-45.
- Scherin, H., Koike, S.T., Laenmlen, F.F. and Van Bruggen, A.H.C., 1995, "Field evaluation of fungicide spray advisories against lettuce downy mildew (*Bremia Lactucaee*) based on measured or forecast morning leaf wetness", *Plant Dis.*, **79**, 511-516.
- Sutton, J.C., James, T.D.W. and Rowell, P.M., 1986, "BOTCAST: A forecasting system to time the initial fungicide spray for managing botrytis leaf blight of onions", *Agric. Ecosys. Environ.*, **18**, 123-143.
- Wilks, D.S. and Shen, K.W., 1991, "Threshold relative humidity duration forecasts for plant disease prediction", *J. App. Meteorol.*, **30**, 463-477.
- Wittich, K.P., 1995, "Some remarks on dew duration on top of an orchard", *Agric. For. Meteorol.*, **72**, 167-180.
- W.M.O., 1988, "Agrometeorological aspects of operational crop protection", WMO Technical Note No., 192.