Estimation of Leaf Wetness Duration Using Empirical Models in Northwestern Costa Rica

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1. Introduction

Implementation of disease-warning systems often results in substantial reduction of spray frequency (Lorente et al., 2000; Madden et al., 2000). This change reduces the burden of pesticide sprays on the environment and can also delay the development of fungicide and bactericide resistance. To assess the risk of outbreaks of many foliar diseases, it is important to quantify leaf wetness duration (LWD) since activities of foliar pathogen depend on the presence of free water on host crop surface for sufficient periods of time to allow infection to occur. Measurement of LWD at few weather stations makes it difficult to obtain reliable LWD data for disease prevention. Even when data are available, spatial variability of wetness duration frequently makes it difficult to use the measurement, especially, at a site more than a few miles distant from the weather station (Rao et al., 1998).

To circumvent some of the limitations of using wetness sensors, models have been developed to estimate rather than measure LWD using energy balance equations, empirical statistical methods (Pedro and Gillespie, 1982; Gleason et al., 1994). However, few efforts have been made to estimate LWD with empirical models in tropical regions, despite potential benefits to local growers who could use the data as convenient inputs to disease-warning systems. In this study, empirical models of LWD developed in the Midwestern US were evaluated in northwestern Costa Rica to find a reliable model to estimate LWD in a tropical region.

2. Materials and Methods

2. 1. Weather data

Air temperature, relative humidity (RH), wind speed, and rainfall were measured at six sites in northwestern Costa Rica (Figure 1). Hourly weather data were observed during April-September 1999 (wet season) and November-April 2000-2001 and 2002-2003 (dry season). Wetness was measured using electrical wetness sensors (Model 237, Campbell Scientific, Logan, UT) deployed facing north at an angle of 45° to horizontal at a height of 0.5 m above managed turfgrass. When a sensor detected < 1000 kΩ for ≥ 30 min in an hour, the hour was recorded as wet (=1); when wetness occurred for < 30 min, the hour was classified as dry (=0).

2.2. Wetness models

Empirical LWD models evaluated in this study included the CART/SLD/Wind model (CART model), Fuzzy LWD model (FL model) and a corrected version of the FL model (CFL model). The CART model was a hierarchical decision tree using dew point depression (DPD), wind speed, and relative humidity (RH) to estimates LWD (Gleason et al, 1994; Kim et al., 2002). Although the FL model was developed and validated in the US Midwest, we attempted to adapt it to northwestern Costa

Rica, which is a tropical region. A weight value, called a correction factor, was applied to the output of the FL model without altering the model algorithm. To determine the correction factor for a tropical area, a data set that contained days on which wetness was recorded was arbitrarily split into ten separate subsets and error of LWD estimation was evaluated in each subset. The correction factor was determined to be a value that minimized root mean square error (RMSE) in LWD estimation among the training subsets

2.3. Analysis of wetness estimation accuracy

To include entire dew-eligible periods, 24-h periods were designated from 12:00 until 11:00 the next day. Measurements from wetness sensors were assumed to represent LWD accurately, and deviations of model estimates from wetness sensor measurements were considered to be errors.

3. Results and discussion

3.1. Occurrence of wetness in the northwestern Costa Rica

Distributions of DPD and VPD values were similar between wet and dry seasons (Figure 2). During dry seasons, however, wetness was recorded more frequently at > 2.0 °C for DPD and > 0.5 kPa for VPD, respectively. Compared with wet hours measured in the US Midwest during April-September of 1997-1999 (Kim et al., 2002), distribution of DPD during wet hours in northwestern Costa Rica

Table 1. Mean error (ME) and Mean absolute error (MAE) of model-estimated wetness duration in northwestern Costa Rica during wet season.

Sites	N[a]	MWD[b]	ME (h/day) (SEM)[c]		MAE (h/day)[d]	
			CART[e]	FUZZY[f]	CART	FUZZY
Overall						
Garza	149	15.0	7.6 (0.20)	2.4 (0.16)	7.6	2.5
Liberia	151	12.4	5.1 (0.27)	0.0 (0.24)	5.5	4.0
Mojica	131	8.1	4.9 (0.29)	0.6 (0.20)	5.2	2.7
Puntarenas	102	12.7	3.5 (0.25)	-1.5 (0.16)	3.6	2.3
Santa Cruz	116	11.8	3.6 (0.20)	0.1 (0.13)	3.9	2.1
All	649	12.0	5.1 (0.13)	0.5 (0.10)	5.4	2.8
Wet Days[g]						
Garza	149	15.0	7.6 (0.20)	2.4 (0.16)	7.6	2.5
Liberia	149	12.6	5.1 (0.27)	0.0 (0.24)	5.5	4.0
Mojica	98	10.8	5.0 (0.30)	0.6 (0.24)	5.5	3.3
Puntarenas	101	12.8	3.4 (0.24)	-1.6 (0.16)	3.6	2.3
Santa Cruz	111	12.3	3.6 (0.20)	0.1 (0.14)	3.9	2.2
All	608	12.9	5.2 (0.13)	0.4 (0.10)	5.4	2.9

a. Number of 24-h periods include in the analysis.
b. MWD = Wetness duration measured during study periods.
c. ME = mean error (Σ(estimated – measured)/N) and SEM = standard error of the mean difference.
d. MAE = mean absolute error (Σ|estimated – measured|/N)
e. CART = the CART/SLD/Wind model (Kim et al., 2002)
f. Fuzzy = the Fuzzy LWD model
g. Wet days indicated days on which wetness ≥ 1h/day was measured.

occurred over a narrower range in both wet and dry seasons (Figure 2). Distribution of VPD, on the other hand, was similar between northwestern Costa Rica and the Midwestern US.

3.2. Estimation of wetness in northwestern Costa Rica

The FL model was the first LWD model incorporating physical equations in the form of logic statements within a fuzzy logic system, which had spatial portability within the Midwestern US (Kim et al., in prep). During the 1999 wet season in Costa Rica, estimation of LWD was far more accurate with the FL model than the CART model (Table 1). However, the FL model was not able to estimate occurrence of wetness correctly during dry season in 2000-2001, which resulted in underestimation during days on which wetness was measured (Table 2). This inability to detect wetness occurrence may have resulted from different weather conditions favoring dew formation between the Costa Rica dry season, compared with the Midwestern US.

The fact that a simple correction factor was able to adapt the FL model to the semi-arid climate of dry season northwestern Costa Rica was shown by relatively accurate estimation of LWD for the corrected compared with original the FL model during the 2002-2003 dry season (Table 3). Improved accuracy using the correction factor suggests that the FL model might be adjustable to any region in the temperate and tropical zone using weather data measured at local weather stations.

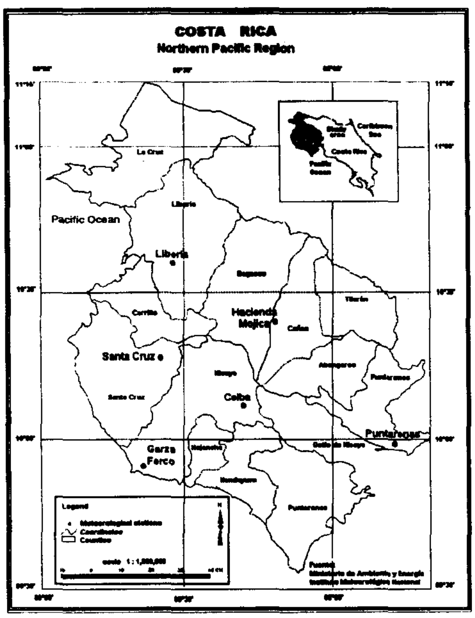

Figure 1. Location of weather station sites in northwestern Costa Rica.

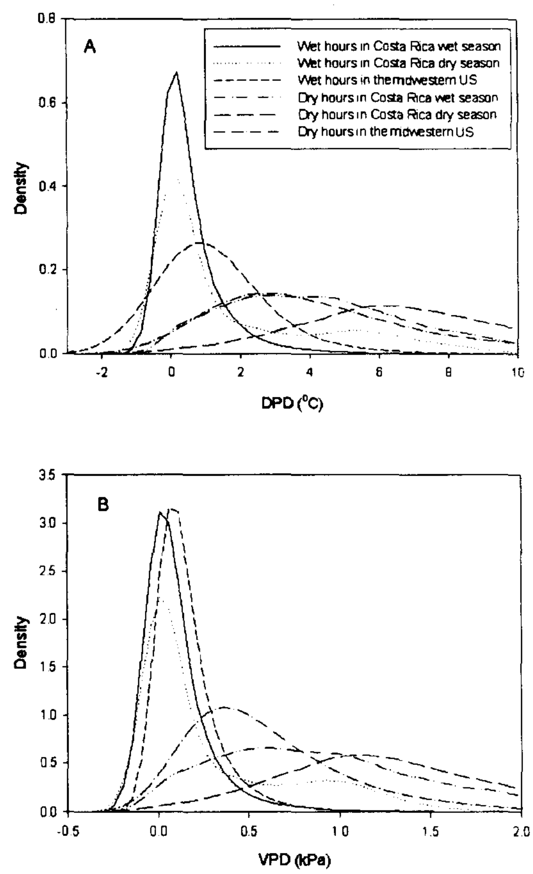

Figure 2. Distribution cf dew point depression (DPD) and vapor pressure deficit (VPD) in northwestern Costa Rica and US Midwest.

Table 2. Mean error (ME) and Mean absolute error (MAE) of model-estimated wetness duration in northwestern Costa Rica during dry season in 2001-2002.

Site	N	MWD	ME (SEM)		MAE	
			CART	FUZZY	CART	FUZZY
Overall						
Ceiba	105	1.5	0.7 (0.34)	-0.7 (0.25)	1.7	1.1
Garza	144	8.9	4.0 (0.26)	0.5 (0.12)	4.0	1.1
Liberia	140	3.2	-0.4 (0.36)	-2.1 (0.31)	3.2	2.5
Mojica	116	2.5	-1.2 (0.37)	-2.0 (0.35)	2.2	2.0
All	505	4.3	0.9 (0.19)	-1.1 (0.14)	2.9	1.7
Wet Days						
Ceiba	28	5.5	1.3 (1.17)	-2.7 (0.83)	5.2	4.1
Garza	124	10.4	4.2 (0.28)	0.5 (0.13)	4.2	1.2
Liberia	68	6.5	-1.8 (0.63)	-4.3 (0.51)	5.8	5.0
Mojica	38	7.6	-4.2 (0.92)	-6.0 (0.72)	6.0	6.2
All	258	8.4	1.1 (0.35)	-2.1 (0.26)	5.0	3.3

* Legend as for Table 1.

Table 3. Mean error (ME) and Mean absolute error (MAE) of model-estimated wetness duration in northwestern Costa Rica during dry season in 2002-2003.

Sites	N	MWD	ME (h/day) (SEM)			MAE (h/day)		
			CART	FUZZY	Corrected[a]	CART	FUZZY	Corrected
Overall								
Ceiba	101	2.0	-0.4 (0.17)	-1.9 (0.32)	-0.4 (0.16)	0.9	1.9	0.9
Liberia	106	4.8	-1.6 (0.18)	-3.6 (0.28)	-1.1 (0.15)	1.9	3.6	1.4
Mojica	101	2.1	-0.9 (0.22)	-1.7 (0.29)	-0.9 (0.22)	1.1	1.7	1.1
Santa	99	2.9	-0.5 (0.17)	-2.1 (0.33)	-0.4 (0.12)	1.0	2.2	0.8
All	407	3.0	-0.8 (0.10)	-2.4 (0.16)	-0.7 (0.09)	1.2	2.4	1.1
Wet Days								
Ceiba	39	5.3	-0.9 (0.44)	-5.0 (0.52)	-1.1 (0.40)	2.3	5.0	2.3
Liberia	81	6.2	-2.0 (0.21)	-4.8 (0.26)	-1.4 (0.18)	2.5	4.8	1.9
Mojica	37	5.8	-2.4 (0.52)	-4.7 (0.51)	-2.5 (0.51)	2.9	4.7	3.1
Santa	38	7.6	-1.4 (0.40)	-5.4 (0.50)	-1.0 (0.29)	2.5	5.8	2.0
All	195	6.2	-1.8 (0.18)	-4.9 (0.20)	-1.5 (0.16)	2.5	5.0	2.2

* Legend as for Table 1.

a. Corrected = the corrected version of fuzzy LWD model by multiplying a correction factor (1.05) to its output.

4. References

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