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Evaluation of a Penman–Monteith approach to provide "reference" and crop canopy leaf wetness duration estimates

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Abstract

Leaf wetness duration (LWD) is a key parameter for plant disease-warning systems since the risk of outbreaks of many plant diseases is directly proportional to this environmental variable. However, LWD is not widely measured so several methods have been developed to estimate it from weather data. Methods based on the physical principles of dew deposition and dew or rain evaporation have shown good portability and sufficiently accurate results for operational use. A Penman–Monteith approach to modeling LWD on a "reference" wetness sensor located at a weather station was investigated as well as the use of an empirical wetness coefficient (W) to convert "reference" LWD into crop LWD. This study was undertaken because recent observations revealed that an LWD sensor located about 30 cm above a turfgrass surface provided useful estimates of LWD in various nearby crops, suggesting that modeling such a sensor and location may be a simpler "reference" alternative to modeling LWD in a crop canopy. LWD was measured over mowed turfgrass at different heights (30, 110, and 190 cm above the ground) and at the top of the canopy of eight crops – apple, coffee, cotton, maize, muskmelon, grape, soybean, and tomato – using painted flat-plate sensors. At the same times and places, automatic weather stations measured air temperature, relative humidity, wind speed, and net radiation over turfgrass. A Penman–Monteith approach estimated sensor LWD over turfgrass with very good accuracy and precision, using an additional aerodynamic resistance based on wind speed to estimate LWD at 110 and 30 cm. The model overestimated LWD by 3.3% at 190 cm ($R^2 = 0.92$), 1.5% at 110 cm ($R^2 = 0.87$), and 5.7% at 30 cm ($R^2 = 0.89$). When modeled LWD for a 30-cm height over turfgrass was correlated with LWD measured at the top of crop canopies, strong agreement was observed, with an average overestimation of 6.3% and a coefficient of determination of 0.92 for five crops combined. The use of both general and specific W coefficients reduced the average overestimation and the mean absolute error in LWD to less than 1 h/day. When independent data from four crops were use to evaluate crop LWD estimates by this two-step Penman–Monteith approach, mean absolute error was <1.6 h when both general and specific W coefficients were used. We concluded that a Penman–Monteith model for a fixed sensor size, albedo and exposure over turfgrass may be a very useful "reference" index to estimate crop LWD for use in plant disease management schemes.

Keywords: Dew; Rain; Physical model; Plant disease; Warning system; Integrated pest management

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1. Introduction

Leaf wetness is recognized as a very important weather parameter for plant disease epidemiology (Pedro, 1980; Huber and Gillespie, 1992; Gleason et al., 1994; Kim et al., 2002). The time that free water remains on the surface of plant tissues, termed leaf wetness duration (LWD), is fundamental for bacterial and fungal disease development, so the risk of outbreaks of many crop diseases is directly proportional to this environmental variable (Huber and Gillespie, 1992). For this reason, LWD, together with air temperature, has been used successfully in many weather-based plant-disease management schemes like Downcast for onions (Jesperson and Sutton, 1987), Tomcast for tomatoes (Pitblado, 1992), Melcast for muskmelons (Latin and Egel, 2001), and others.

Because LWD is not widely measured, several methods have been developed to estimate it from weather data (Pedro and Gillespie, 1982a,b; Huber and Gillespie, 1992; Gleason et al., 1994; Rao et al., 1998; Sentelhas et al., 2004a; Magarey et al., 2005). Methods based on the physical principles of dew deposition and the evaporation of dew or intercepted rain have shown good portability and sufficiently accurate results for operational use. Examples of application of physical models of LWD include maize, soybean, and apple (Pedro and Gillespie, 1982a,b), onion (Gillespie and Barr, 1984), sunflower (Garín et al., 1997), banana plantation (Lhomme and Jimenez, 1992), apple (Wittich, 1995), maize ears (Rao et al., 1998), grapes (Magarey, 1999, and Dalla Marta et al., 2005), rice (Lou and Goudriaan, 1999, 2000), and canola (Papastamati et al., 2004). However, these models require net radiation (R_n) as input, which is seldom measured directly over crops or even in a standard weather station (Madeira et al., 2002). When direct measurements of R_n are not available, R_n estimates can be based on combinations of incoming solar radiation, air temperature, relative humidity, cloud cover, and cloud height (Pedro, 1980; Jegede, 1997; Iziomon et al., 2000; Madeira et al., 2002).

Among the physical models used to estimate wetness deposition and evaporation, the one based on the Penman–Monteith equation (Monteith and Unsworth, 1990) has some advantages in relation to those based on an energy balance approach (Pedro and Gillespie, 1982a,b). The main advantage is elimination of the requirement for an air temperature measurement at crop (leaf) level. The Penman–Monteith approach assumes that air temperature measured at a given height above turfgrass at a standard weather station is equivalent to temperature at the same height above the top of a crop canopy, and that adding a resistance item to the model is enough to account for the air layer from measurement height, above the canopy, to the level of the leaves (Rao et al., 1998). Results of Lou and Goudriaan (1999, 2000) in a tropical region of Phillipines, Jacobs et al. (2002) in an arid Mediterranean region, Rao et al. (1998) in southern Canada, and Sentelhas et al. (2004a) in a tropical region of Brazil, have shown that Penman–Monteith approaches estimated LWD very well under diverse climatic conditions.

According to Zhang and Gillespie (1990), estimation of crop LWD with weather data taken outside a crop field could be a two-step process where a "correction" is first applied to the station data before using it in a crop model. Considering this idea, and the recent results presented by Sentelhas et al. (2004b, 2005) which showed that LWD measurements at 30 cm over turfgrass were very similar to those obtained near the top of five different crop canopies of different height and architecture (apple, coffee, maize, grape, and muskmelon), it was hypothesized that a "reference" LWD, estimated by a Penman–Monteith approach using weather data, could provide an accurate estimate of crop LWD when multiplied by a wetness coefficient, similar to the process used to estimate crop evapotranspiration (Allen et al., 1998). To test our hypothesis the following goals were set:

(a) Evaluate a Penman–Monteith approach to modeling LWD on a wetness sensor located in a standard weather station to provide a simple "reference" LWD.
(b) Compare estimated "reference" LWD with measured crop LWD obtained in five different nearby crop canopies: coffee, grape, maize, soybean, and tomato.
(c) Assess the ability of an empirical wetness coefficient (W) to convert "reference" LWD into crop LWD.

2. Material and methods

2.1. Leaf wetness duration measurements

Leaf wetness duration measurements over turfgrass and at the top of the crop canopies were done with flat plate sensors (Model 237, Campbell Scientific, Logan, UT) connected to dataloggers (Models 21X and CR23X, Campbell Scientific, Logan, UT) programmed to measure the percentage of time in which the sensors were wet during each 15-min interval. Each sensor used in this study was painted with two or three coats of