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J1.3 CONSIDERATIONS FOR DETERMINING LEAF WETNESS USING INFRARED THERMOMETRY IN HUMID REGIONS

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1. INTRODUCTION

Wet conditions on leaves promote disease development, decreasing quality and quantity of harvested crops. Difficulties in creating reliable wetness sensors have encouraged development of innovative techniques to detect or infer leaf wetness. A recent publication (Deshpande et al., 1995) points out that leaf wetness duration can be estimated using infrared thermometry. In summary, they proposed that when the leaf temperature rises above the dew point, the leaf has dried. This procedure was tested and found reliable for the conditions within dry bean canopies in western Nebraska. Observations and data suggest that this procedure may underestimate leaf wetness duration in humid regions. A combination of theory and empiricism indicates that their method can be refined and thus generalized for use in more humid areas. The objectives of this work are to state the theoretical basis for the refinement and to list practical considerations for using the infrared thermometer method in humid areas.

Theoretically, the canopy goes through four stages in the early morning. It 1) accumulates moisture when at the dew point, 2) is drying but still wet when at the wet bulb, 3) is partly wet and partly dry while the temperature rises to a point 4) at which transpiration determines the balance with the environment and the canopy temperature is relatively steady. These stages can be seen on a plot of canopy minus air temperature vs. vapor pressure deficit if the points are identified over time. In our experience, there has often been 1) a cluster of points below the dew point depression and essentially zero VPD, 2) another cluster at the wet bulb depression and zero VPD, 3) a trend upwards and to the right, and 4) a horizontal trend thereafter. We have attributed these patterns to the four stages described above (Evans and Sadler, 1987). For light dew, the duration of the stages 2 and 3 may be very short, which would support use of Deshpande et al's (1995) method. If duration is measured in hours, a few minutes error is academic. Under other circumstances, however, the error may be significant, and it is quite easy to modify the procedure if desired.

Experiences in the humid SE USA are that dew is both common and quite heavy. It is common to have morning ground fog, and we have measured energy balances for which the fog was not dissipated before 1100 hr. Field work, fall harvests, lawn mowing, and outdoor recreational activities all are affected by dew in addition to its effects on pathogen spread and growth. Under these conditions, there appears to be a need for determining the usefulness of Deshpande et al's (1995) method, in particular whether the endpoint should be delayed until the leaf temperature exceeds the wet bulb rather than dew point temperature. Data sets obtained in earlier studies (Sadler and Kustas, 1989) provided us a means to test the method under our conditions.

2. MATERIALS AND METHODS

The SE USA Coastal Plain is characterized by small fields often bordered by pine trees that limit fetch. Humidity is high, irradiance is variable, wind speed is low, and rain is frequent. From 1986 to 1990, energy balance measurements were made at Florence, SC, as part of an ongoing effort to determine adequacy of techniques developed and tested in other regions. Bowen ratio energy balance, residual energy balance, stem gauge, and soil water balance methods have been used to measure ET with varying degrees of success. Because of the variability of the environment, all measurements were taken four times a minute, averaged, and stored for the minute. The techniques required averaging for 15- to 20-min periods, but the original data provided interesting insights that placed confidence limits on our methods and guided other research. For this illustration, a 1987 soybean data set was chosen, which extended from 16 Sep to 11 Oct, with 22 days suitable for this study.

All electrical signals were measured using programmable data loggers. Air temperature and wet-bulb depression were measured using either a dry type-T thermocouple differentially wired with another in an aspirated ceramic wick or 500-ohm PRT's housed similarly. Canopy temperature was measured using two infrared thermometers (Everest Interscience, Tustin, CA; model 4000, 4° field of view[2]) arranged at 45° from nadir, one facing east and the other west. Other measurements included wind speed and direction, solar irradiance, net radiation, soil temperature, and soil heat flow. Although no measurements of leaf wetness were taken, one may still determine the effect of changing the method on duration.

3. RESULTS AND DISCUSSION

A plot of air, soybean leaf, wet bulb, and dew point

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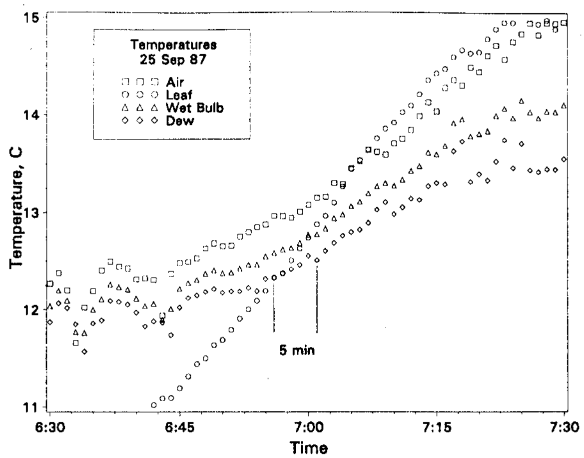

Figure 1. Representative air, leaf, wet bulb and dew point temperatures.

temperatures near dawn on 25 Sep 1987, a representative day, is shown in Figure 1. For this day, the error in assuming a dry canopy when the canopy temperature exceeded dew point (0656 hr) instead of the wet bulb (0701 hr) was 5 min. This error ranged from essentially zero to an extreme in this data set of 20 min. In this example, the point when the plot of canopy-air temperature difference against vapor pressure deficit showed the change from the rising trend to the horizontal occurred about 8-12 min later (Fig. 2). This endpoint is subject to variation and would be very difficult to automatically detect. This endpoint has been assumed to be when the canopy first is completely dry. Note that the leaf temperature exceeds air temperature (Fig. 1), which is common under the humid conditions of the area (Evans and Sadler, 1987; Sadler and Kustas, 1989; Sojka et al., 1990).

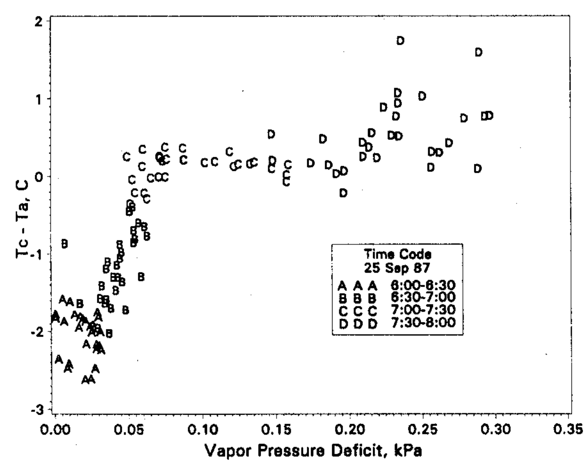

Figure 2. Time trend of canopy-air temperature difference plotted against vapor pressure deficit.

It may be possible to measure leaf temperature in a manner that allows detection of the time that the last wetted areas dry entirely. Consider 2 infrared thermometers pointed down at 45° from nadir. During sunrise, an east-facing device would have shaded leaves in view, and the west-facing one would have sunlit leaves in view. The west-facing IRT has a higher temperature than the east-facing IRT, and in the example above for 25 Sep, leaf temperature crossed both the dew point and wet bulb 11 min prior to the corresponding times for the east-facing IRT. For the 22 days sampled, the minimum difference was 0 min; the maximum, 23 min; and the median, 12 min.

4. CONCLUSIONS

Water accumulates on leaves whenever the leaf temperature is at or below the dew point temperature. While the surface is wet but the moisture flow is away, the leaf temperature is near the wet bulb temperature. For some conditions, during which a significant dew point depression exists, attributing the endpoint to the rise above dew point causes an underestimated duration, because the leaf is wet until the temperature rises above the wet bulb. Practically speaking, however, these conditions are not overly common, because the evaporation of water from leaves causes the local air, wet bulb, and dew point temperatures to converge at the time the leaf temperature rises above the dew point. The published method would not usually be in error by more than about 10 min; the maximum observed was about 20 min. This error is probably insignificant for most applications, but the correction to employ the wet bulb instead of the dew point is very simple. A second, more important consideration is that a canopy does not dry everywhere simultaneously. Sunlit areas dry earlier than shaded areas, as can be seen using infrared thermometers facing both east and west at 45° from nadir. If one desires the full extent of leaf wetness, one could use an infrared thermometer facing east to determine the end of leaf wetness. Conversely, the onset of dew in the evening should probably be judged using a west-facing infrared thermometer. Though there would probably be some additional lag deep within the canopy, these simple changes should improve the estimated duration. In summary, the published method, with attention to the above, appears to have real value as an advancement in determining duration of leaf wetness.

5. REFERENCES

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