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Precipitation and dew in a soybean canopy: Spatial variations in leaf wetness and implications for *Phakopsora pachyrhizi* infection

Hans F. Schmitz *, Richard H. Grant

Department of Agronomy, Purdue University, 915W. State St., West Lafayette, IN 47907, United States

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ABSTRACT

With the occurrence of soybean rust (*Phakopsora pachyrhizi*) now a seasonal problem in the United States, increased research is needed to ascertain the potential transmission of this disease among soybean (*Glycine max* L.) in major growing regions throughout the nation. The fungal disease spores are deposited on leaves in the lower region of the canopy through rain events or wind transport from nearby plants during the growing season and must then have moist conditions on the lower trifoliolates for several hours in order to infect the plant. These moist conditions can be achieved through any form of wetness. This wetness was measured in a soybean canopy at West Lafayette, IN, during the summer of 2007 using resistance-grid wetness sensors located at three heights representative of the top, mid-level, and lowest trifoliate of the canopy. Temperature, relative humidity, wind speed, and precipitation measurements were used to determine the cause of wetness. Over the course of the experiment, wetness events were classified as dew, rain, or neither. The dew events were then compared to rain events with an emphasis on differences in vertical and horizontal duration of wetness. Dew events were found to be the dominant wetness source in the upper canopy. Rain events were the most dominant cause of wetness in the lower canopy. Upper canopy wetness events had the longest duration. Horizontal variation in wetness and wetness duration was large.

1. Introduction

With the increasing occurrence of soybean rust (*Phakopsora pachyrhizi*) in the United States, an understanding is needed of the potential for transmission of this disease among soybean (*Glycine max*) in major growing regions throughout the nation. The fungal spores are deposited on leaves in the lower region of the canopy through rain events or wind transport from nearby plants during the growing season and must then have moist conditions on the lower trifoliolates for at least 6–12 h in order to infect the plant (Huber and Gillespie, 1992). These moist conditions can be achieved through any form of wetness, i.e. drizzle, mist, fog, rain, or dew. The minimum duration of wetness is dependent on the ambient temperature after spore deposition (Melching et al., 1989). Temperatures of 18–26.5 °C were found to produce optimal lesion formation, with no rust lesions produced at temperatures outside of the 10–26.5 °C range (Melching et al., 1989). Many other researchers have noticed the correlation of dew and fungal disease spread in crop canopies, notably Van der Wal (1978).

Rainfall of sufficient intensity can immediately penetrate and wet an entire crop canopy. The interaction between dew and the canopy is a less understood phenomenon. Referring to Garratt and Segal (1988) and Monteith (1957), liquid water condensation during a night without precipitation can occur due to dewfall, dew-rise (or distillation), or guttation. Guttation is a release of moisture onto the plant surface by the plant itself through internal mechanisms, and is generally neglected when considering sources for dew. Dewfall is the condensation flux of atmospheric water vapor to the surface of the leaf, essentially occurring first in the area most affected by atmospheric humidity, the top of the canopy. Dew-rise or distillation is the flux of water vapor from a moist soil to the air, increasing humidity and causing condensation on the leaf surface. This process also may occur by diffusion of vapor from the soil to the leaf surface, most commonly observed with turf grasses or grass-like crops. In order for dew to form, the temperature of the leaf surface must cool below the dew-point temperature of the surrounding air, thus allowing for condensation of excess moisture onto the surface of the leaf. Typical wetness accumulation on the leaf by dew overnight is slight (0.4 mm) compared to most precipitation events, but can be a significant factor in disease development.

Estimates of leaf wetness duration (LWD) via rain, dew, or irrigation have been determined using various methods, ranging

* Corresponding author. Tel.: +1 812 4837554; fax: +1 812 7234196.
E-mail addresses: hschmitz@purdue.edu, h.f.p.schmitz@gmail.com (H.F. Schmitz), rgrant@purdue.edu (R.H. Grant).

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from models derived using nearby weather station data (Pedro and Gillespie, 1982b) to sensor analysis at canopy height in the field (Pedro and Gillespie, 1982a; Weiss et al., 1989; Armstrong et al., 1993). Many differing single (Monteith and Butler, 1979; Payen, 1983) and multi-layer (Huber and Itier, 1990; Norman, 1979; Thompson, 1981) models have been created and used to estimate LWD and/or dew duration, many with an error of less than 60 min. These models are complex by nature, and are frequently compared to the results of either visual monitoring or wetness sensor data (Wichink Kruit et al., 2004; Huber and Itier, 1990).

Research to characterize the variability of leaf wetness duration has occurred in apple trees and grapevines (Batzer et al., 2008; Dalla Marta et al., 2008). Both studies found a large amount of heterogeneity based on sensor placement within the respective canopies (Batzer et al., 2008; Dalla Marta et al., 2008). Characterization of the variability in leaf wetness duration of a dense, relatively uniform canopy was the goal of this study. The study was performed in order to determine the canopy-scale horizontal and vertical differences in the formation of dew in a soybean canopy and the dry-down period following a dew or precipitation event. Resistance-grid sensors were used to attain estimates of leaf surface wetness in the canopy at three heights. Of main interest was the lower canopy, where most soybean rust disease initiation occurs.

2. Materials and methods

The study was conducted at a field of Pioneer 93M10 Round-up Ready soybean at the Purdue University Agronomy Center for Research and Education (40.5°N, 86.9°W). Soybean were drilled with a 7.5 in. (190 mm) row spacing on May 10, 2007. On 12 June, the field was sprayed with glyphosate and fluazifop for weed control. A temperature and relative humidity sensor (Vaisala, Model HMP35C; Vantaa, Finland) was located at a height of 1.05 m above ground. A cup anemometer (WeatherMeasure WeatherTronics, Model 2031; Sacramento, CA) was located at a height of 1.3 m. Measurements were recorded every 180 s using a Campbell Scientific 21X datalogger (Campbell Scientific, Inc.; Logan, UT). Wetness sensors were checked for accuracy before and after the experiment, while in-field datalogger checks confirmed accuracy of the other instruments. Precipitation measurements were taken by permanent rain gauges located approximately 150 m from the measurement site.

2.1. Wetness sensors

Resistance-grid wetness sensors (Gillespie and Kidd, 1978) were custom-made by Shoemaker Technologies (Lafayette, IN). The sensors were 50 mm wide by 140 mm long and etched with a grid of 1 mm wide copper traces at 1 mm of spacing. The sensor's resistance-grid was coated with one coat of black latex spray paint, followed by two coats of white latex spray paint (Lau et al., 2000). This created a sensor less susceptible to humidity fluctuations and more retentive of moisture. Response to wetness was then verified in the laboratory. The sheen of the latex paint caused the moisture to shed off the sensor surface before it could penetrate and be recorded. To correct this observed error, the sensors were lightly sanded to increase surface roughness before placement in the field.

In the field, sensor angles were fixed at 30° off horizontal facing south using wooden stakes at heights of 250, 550, or 850 mm above the soil surface (Lau et al., 2000). The locations of the sensors were randomly determined using SAS (SAS Institute; Cary, NC). The lengths of sensor wiring, either 5 ft (1.5 m), 15 ft (4.6 m), or 30 ft (9.1 m) limited stake placement. Stake heights within each of the three wire-length circles alternated from 250 to 550–850 mm high traveling from west to east. The resulting experimental area was a circle with a 30 ft (9.1 m) radius (Fig. 1). The sensors were placed in the field on 27 June.

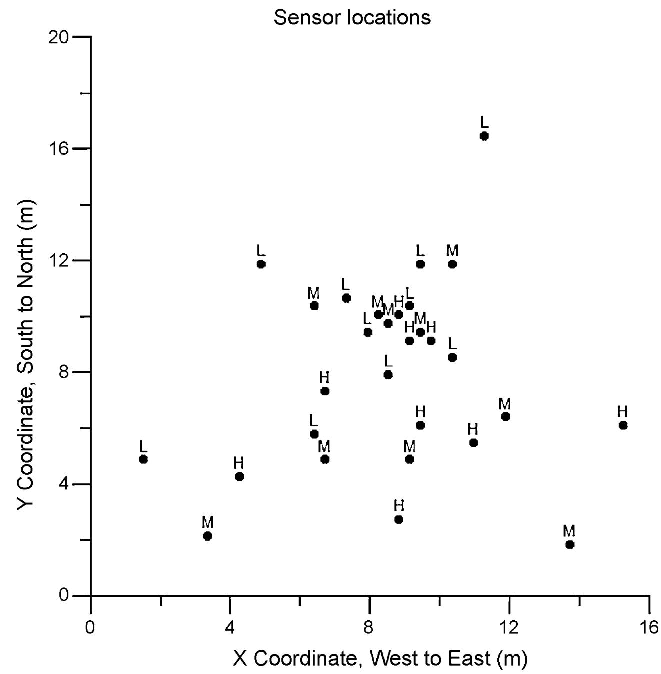

Fig. 1. The locations of the stakes and sensors in the field. Sensor height is denoted by *L* (25 cm), *M* (55 cm), or *H* (85 cm). Traditional directional coordinates are followed.

The measurements were sampled every second, and mean values recorded every 180 s. Data were collected from 9 July until 11 September 2007. Mean canopy height on 9 July was 575 mm. The sensors placed on 850 mm stakes were disregarded in data collection until the canopy reached 850 mm on 21 July. Mean canopy height at site teardown on 11 September was 1.01 m.

Each sensor had a unique output due to slight variations in the resistance of the circuit and the thickness of the latex paint on the sensor's surface. Since difference in wetness between sensors could be due to both position in the canopy and sensor response, all sensor responses were calibrated for difference between response when dry or when wet. Sensor wetness was assured by a heavy rainstorm that wet all sensors during the same period of time. This storm was preceded by a dry period that assured all sensors were dry. The range of sensor response over a representative 7-day period was analyzed for the high and low values of each sensor. Values were measured in units of inverse resistance, therefore a decrease in resistance across the board when wet would return a greater output value from the datalogger. The inverse resistance threshold above which a sensor was "wet" was calculated using $R_{th} = 0.64(R_{max} - R_{min}) + R_{min}$, where R_{th} is the threshold and R is the individual sensor response. The 0.64 coefficient was an arbitrary fraction that fits well to sensor response in events of heavy and immediate rain. Every data point that exceeded the threshold was flagged as "wet." The duration of wetness was calculated by summing adjacent "wet" data points. The starting times and ending times of each wetness period were related to precipitation, wind, temperature, and relative humidity conditions to give insight in the processes involved in canopy wetting and drying.

The response of each sensor to wetness was verified after removal from the field. Rainfall and wind data were collected from a weather station approximately 100 m from the site and used for anemometer comparison and data interpretation. Several wetness sensor wires were chewed through by field mice nesting in the