Electronic Circuit for Detecting Leaf Wetness and Comparison of Two Sensors

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ABSTRACT

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An inexpensive, easily constructed circuit for detecting leaf wetness operates on a frequency, which is a function of the amount of moisture on a sensor, to voltage conversion. Using this circuit the performances of two sensors were compared under field conditions. One sensor was a printed circuit board on which a grid network was etched and then painted with latex paint. The other sensor used a piece of white cotton cloth as an artificial leaf on a grid network of fine wires; its performance was superior under all conditions that caused leaf wetness.

Additional key words: duration of leaf wetness, microclimate

The duration of leaf wetness is an important factor in the relationship between microclimate and plant disease (8,9) since dew, a source of leaf wetness (7,14,15), influences plant growth and health.

Mechanical leaf wetness recorders do not give consistent results (5). Leaf wetness can be measured electronically by attaching a sensor directly to a leaf or by using a simulated leaf as a sensor. Gillespie and Kidd (3) and more recently Smith and Gilpatrick (12) adapted the sensor and improved the electronic circuit proposed by Davis and Hughes (2) to measure leaf wetness indirectly. The sensor consists of a grid network etched on a printed circuit board. The board was painted with latex paint, the resistance of which varied as a function of the moisture on the board. The electronic circuit supplied a small alternating current to avoid polarization of the water and to minimize self-heating of the board. Any electronic circuit with these types of sensors for measuring leaf wetness must meet these requirements.

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Leaf wetness has been measured directly with microclips (6) and by placing a leaf between a wire grid and wire insulation (4).

Gillespie and Kidd (3) proposed an AC and a DC circuit to measure leaf wetness. Both circuits operated with a fixed voltage and frequency, and the current across the sensor varied as a function of the moisture on the sensor. Melching (6) described a battery-operated circuit with fixed frequency but voltage varying as a function of leaf wetness.

The circuit we used operates at fixed voltage and varying frequency. Its advantages are simplicity of design, ease of construction, and low cost. The circuit can be powered by batteries or line voltage.

MATERIALS AND METHODS

Electronic circuit. The circuit (Fig. 1) for this system consisted of three stages: an oscillator, a precision timer operating

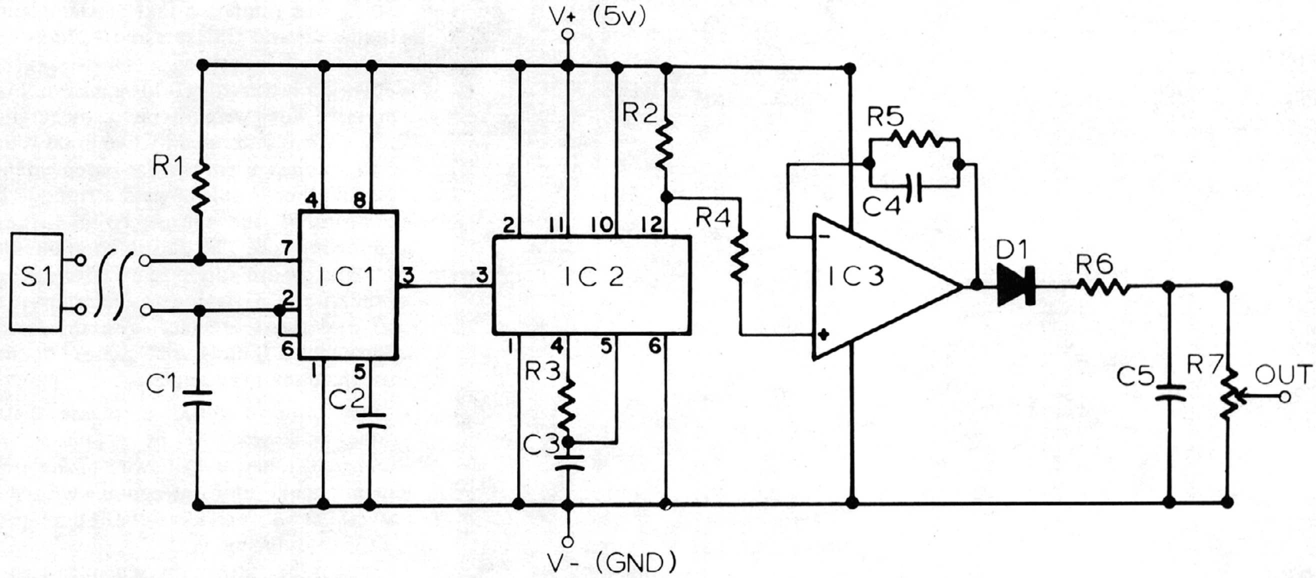

Fig. 1. Schematic of the circuit used to detect leaf wetness. Components: C1 = 0.01 μf, 5%, 250 V WDC; C2 = 0.01 μf, 20%, 250 V WDC; C3 = 33 pf, 20%, 250 V WDC; C4 = 0.01 μf, 20%, 250 V WDC; C5 = 4.7 μf, 20%, 15 V WDC; R1 = 30 kΩ, 1/4 W 5%; R2 = 3.3 kΩ, 1/4 W 5%; R3 = 1 mΩ, 1/4 W 5%; R4 = 20 kΩ, 1/4 W 5%; R5 = 33 kΩ, 1/4 W 5%; R6 = 10 kΩ, 1/4 W 5%; R7 = 50 k trimpot; S1 = sensor board; IC1 = LM 555 timer; IC2 = LM 322 timer; IC3 = LM 3900 quad current differencing amplifier; and D1 = 1N914.

as a monostable multivibrator, and an op-amp integrator. The output frequency of the oscillator stage is directly related to the amount of moisture on the sensor. The monostable multivibrator changes this frequency to a series of constant amplitude, constant duration pulses at the original frequency. These pulses are the input to the op-amp integrator. The output of this last stage is a DC signal directly proportional to the original frequency and thus the moisture on the sensor.

The value of R1 may have to be varied to obtain the desired output frequency from the oscillator stage when the sensor is saturated. This is necessary to compensate for the variation of the resistance of different sensors at saturation, the variability in the value of C1, and the length of cable between the sensor and the circuit. If the output of the circuit is not zero when the sensor is dry, another diode can be added in series with D1 to make the output zero. The value of R6 can be reduced to decrease the output impedance of the circuit to increase the current available to the recording device.

The pulse duration time, determined by R3 and C3, should be about 90% of one cycle of the waveform out of the oscillator at sensor saturation. This is necessary to insure that no cycles are missed by the monostable multivibrator. If the pulses are too narrow, however, maximum voltage out of the integrator will not be realized.

For AC operation, a 5-V power supply can easily be constructed (1,11,13). For DC operation, a 12-V battery can be used to power the circuit through the voltage regulator stage and also to drive a DC-powered strip chart recorder. The total power consumption by the four channels when the sensors are saturated is approximately 153 mW. The power dissipated across an individual circuit board at saturation is about 13 μW.

A circuit was constructed for four channels of leaf wetness data. Based on 1979 prices, the cost per channel for this circuit was about $7.35. Individually shielded, twisted pair cables should be used for each sensor, with the shield grounded at the common terminal of the circuit board.

Table 1. Duration of leaf wetness, as measured by sensor A and sensor B, during clear skies or rain, 13–21 September 1979

September		Sensor A		Sensor B		Difference (sensor A − B) (hr:min)
Begin	End	Time (MST)	Duration (hr:min)	Time (MST)	Duration (hr:min)	
		Clear skies				
14		1609		1913		
	15	0953	17:44	0831	13:12	4:32
15		2148		2143		
	16	0857	11:09	0807	10:24	0:45
17		0047		0042		
	17	0848	8:01	0730	6:48	1:13
17		2318		2318		
	18	0906	9:48	0806	8:48	1:00
19		0401		0400		
	19	0532	1:31	0512	1:12	0:19
19		1515		1644		
	19	1929	4:14	1902	2:18	1:56
Total			52:27		42:42	9:45
		Rain				
13		1327		1355		
	14	1227	23:00	1130	21:35	1:25
20		0842		0842		
	20	0957	1:15	1000	1:18	−0:03
20		1022		1022		
	20	1537	5:15	1516	4:54	0:21
20		1740		1624		
	21	0911	15:31	0848	16:24	−0:53
Total			45:01		44:11	0:50

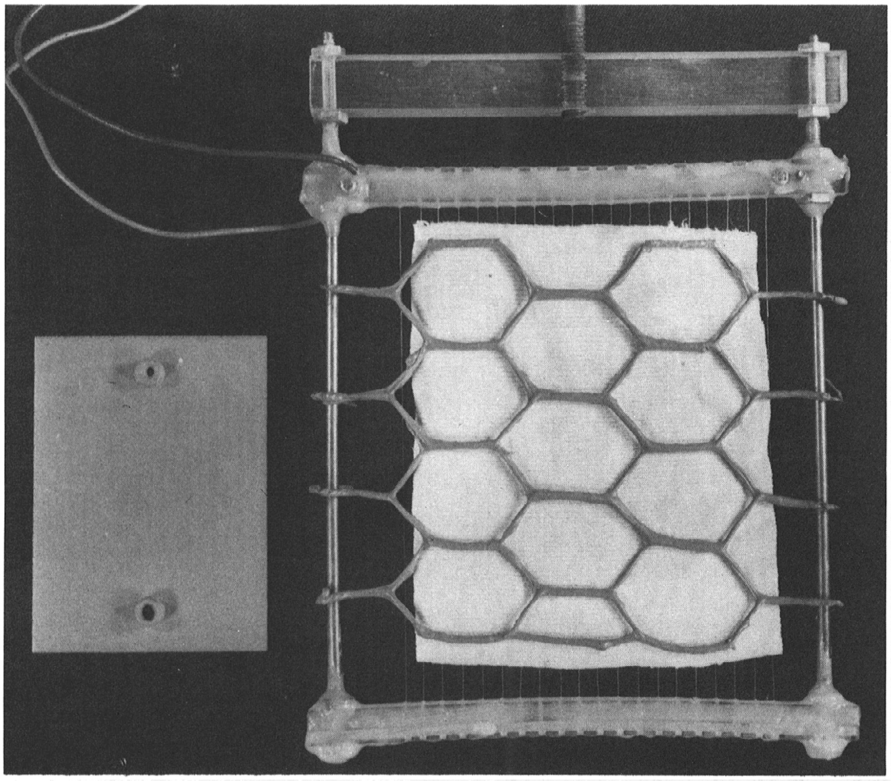
Fig. 2. Sensors for detecting leaf wetness: Sensor A (right). Sensor B (left).

Sensors. We compared two sensors using the above circuit. The first sensor (A) was a variation of the one described by Häckel (4) and the other (sensor B, Fig. 2) was similar to that of Davis and Hughes (2) and Gillespie and Kidd (3).

Sensor A consisted of a wire grid network constructed of 0.13-mm Evanohm wire; two wires were interlaced on acrylic plastic strips separated by two brass rods so that adjacent wires were independent of each other. A third plastic strip is used to connect the frame to a larger supporting rod. The plastic components of the frame are potted to avoid shorting of the wires. This frame was placed over a leaf and fixed in place with insulated chicken wire. If moisture is present on the leaf, the circuit is completed.

We found it difficult to use these frames on leaves of dry beans (*Phaseolus vulgaris* L.), because the wire of the grid did not make uniform contact with the leaves. Leaves were occasionally damaged by the grid during wind.

Rather than attach this sensor to a leaf, we used a piece of white cotton cloth, 0.76-mm thick, as an artificial leaf. The emissivity of the cotton cloth is nearly equal to that of alfalfa (0.98). The cloth and grid network measured approximately 9 × 11 and 9 × 14 cm, respectively. The entire frame was 12 × 16.5 cm, and spacing between adjacent wires was 5 mm. When the cotton cloth became wet, it made uniform contact with the wires. The sensor had to be inspected daily to insure that animals had not disturbed the cotton cloth. Animal damage probably can be overcome by sewing the cloth onto the wire grid.

Sensor B (part A.R.C.P.-1, Wong Laboratories, Cincinnati, OH 45209) consisted of a printed circuit board 5.8 ×7.8 cm and 1.59 mm thick, on which a grid network was etched. This sensor was painted with two thin coats of a light gray latex paint. The width of each grid element and the distance between grid elements was approximately 2 mm. Gillespie and Kidd (3) spaced grid elements 1 mm apart and modified the shape of this sensor to detect leaf wetness in corn (*Zea mays* L.) and onions (*Allium cepa* L.).

Field testing. During our 13–21 September 1979 study, two 30-cm diameter circles were cleared near the center of a 3.7-ha field of alfalfa (*Medicago sativa* L.). A sensor of each type was placed at a height of 15 cm in each circle. Sensors were oriented horizontally and tilted slightly so that water would not accumulate on them. The output from each sensor was recorded on a strip chart recorder (Rustrak, Model 288). The average height of the alfalfa was 64 cm on 11 September 1979.

RESULTS AND DISCUSSION

Occurrences of leaf wetness were categorized as (1) those related to rain or (2) those caused by radiative cooling when the sky was clear (Table 1). Sensor A measured 1.8 and 18.6% longer duration of leaf wetness than sensor B in categories 1 and 2, respectively. Both sensors responded equally well to the onset of rain. The resultant trace on the strip chart recording appeared as a step function.

Visual observations of leaf wetness in the alfalfa compared with leaf wetness detected by sensors A and B are summarized in Table 2. Sensor A observations were in complete agreement with the visual observations; those of sensor B agreed with 10 of 13 observations. On 13 September, sensor A recorded the beginning of leaf wetness caused by light drizzle at 1327 hours (Table 1); the National Weather Service, 12.5 km southeast of our field site, noted light rain showers beginning at 1331. Sensor B indicated leaf wetness 28 min later than sensor A. This discrepancy in the onset of leaf wetness may be attributed to the ability of the sensors to absorb moisture, differences in exposure of the sensors, or a combination. Sensor A's cotton cloth is highly absorbent, but water on the surface of sensor B must first permeate the latex paint before the resistance changes.

Table 2. Visual observations of leaf wetness in alfalfa compared with leaf wetness detected by sensors A and B, 13–20 September 1979

September	Time (MST)	Leaf wetness		Visual observation
		Sensor A	Sensor B	
13	1327	Yes	No	Light drizzle
13	1415	Yes	Yes	Rain
13	1620	Yes	Yes	Rain
14	0730	Yes	Yes	Fog
14	0755	Yes	Yes	Slight moisture on leaves in lower half of canopy, heavy amount in upper half of canopy
14	0955	Yes	Yes	Sunshine, alfalfa slowly drying
14	1804	Yes	No	Slight moisture on leaves in lower half of canopy
18	0835	Yes	No	Slight moisture on leaves in lower half of canopy
19	1800	Yes	Yes	Slight moisture on leaves in lower half of canopy
19	1825	Yes	Yes	Slight moisture on leaves in lower half of canopy, upper half dry
20	0842	Yes	Yes	Light drizzle
20	1800	Yes	Yes	Slight moisture on leaves
20	1833	Yes	Yes	Leaves still wet

Leaf wetness in the plant canopy was variable (Table 2). Sometimes the upper half of the canopy had greater amounts, lesser amounts, or no moisture on leaf surfaces compared with the lower half of the canopy.

On two occasions in the late afternoon, under a clear sky, sensor A indicated leaf wetness. Small water droplets were apparent on the cotton cloth when observed at a low angle of elevation in the direction of the sun. Although signs of water were not visible on the leaves, the leaves did feel cool. We attribute this difference between leaf wetness detected by sensor A and by visual observations to a very thin layer of water on the leaves. Quite possibly in these cases, the dew point temperature of the air was only slightly greater than the leaf temperature. Schein (10) alluded to the importance of a thin film of moisture on a leaf surface for spore germination. On a few occasions, neither sensor detected leaf wetness although large, isolated droplets of water were observed on leaf surfaces in the lower part of the plant canopy. This can probably be overcome by connecting a few sensors in parallel at different orientations.

The cotton cloth of sensor A is a better sensing material than the materials that make up sensor B. Sensor B is approximately twice as thick as the cotton cloth and does not allow airflow through it. Thus, heat storage may be a deleterious factor to the operation of sensor B. Furthermore, the entire cotton cloth is the active element in sensor A, whereas only a thin layer on the circuit board in sensoı B detects leaf wetness.

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