An Aspiration System for Meteorological Sensors Used in Epidemiological Studies

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ABSTRACT

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Temperature and relative humidity measurements that reflect actual environmental conditions often require sensors that are aspirated and shielded from radiation. A simple, inexpensive meteorological aspiration system was designed for field use with an automatic electronic data logging device. The aspiration system requires 12-V DC batteries. The entire aspiration system was constructed from PVC (polyvinylchloride) pipe, which is inexpensive, easy to work with, and available in a variety of sizes. This system should provide a highly accurate data base with which the effects of environmental conditions on disease development can be assessed.

Complete and accurate measurement of environmental parameters is essential to the characterization of plant disease epidemics. Both quantitative and qualitative descriptions of host and pathogen environments are essential for understanding the relationships of weather and plant disease. With the increased emphasis on plant disease simulation models, the need for high quality meteorological data is greater than ever.

In the past, plant pathologists have been hampered in the procurement of accurate environmental data in remote locations mainly by the lack of appropriate data logging equipment. Historically, the accuracy of much environmental data has been suspect because the mechanical sensors that were used are slow to respond, hard to calibrate, and difficult to properly shield and aspirate. These sensor systems are also difficult to place at the site of biological activity, and data comparison from one mechanical system to the next is difficult.

Recent advances in the design of battery-operated, microprocessor-driven data loggers and the interfacing of them with microcomputers now allow the epidemiologist to collect, integrate, and process data efficiently. This paper describes the construction, use, and testing of an aspiration system for meteorological sensors that was operated in conjunction with a Campbell Scientific Micrologger System model CR-21 (Campbell Scientific Inc., Logan, UT 84321) (Fig. 1C). This system is being widely used by plant pathologists working in remote locations; in the present case, it was used to study the effects of environment on the epidemiology of fusiform rust (*Cronartium quercuum* (Berk.) Mujabe ex Shirai f. sp. *fusiforme*) at a field site located in the Sand Hills State Forest near Patrick, SC. The aspiration system described in this paper can be used with almost any data logging system.

MATERIALS AND METHODS

To increase the accuracy of temperature and relative humidity (RH) measurements, sensors often must be both aspirated and shielded from radiation. The purpose of aspiration is to ensure that the air within the sensor housing unit is representative of the nearby ambient air. If the aspiration rate is too low ($<1\ \mathrm{m{\cdot}s^{-1}}$) this equilibrium will not be accomplished quickly, if at all. Too high an aspiration rate could, in a plant canopy for example, affect the environmental conditions one is attempting to measure. The recommended aspiration rate is between 1 and 3 $\mathrm{m{\cdot}s^{-1}}$ (1). Shielding from solar radiation is required to prevent the sensors from heating up; an unshielded thermistor exposed to solar radiation will record a temperature substantially above the air temperature it is supposed to be measuring.

The aspiration system described in this paper was installed on

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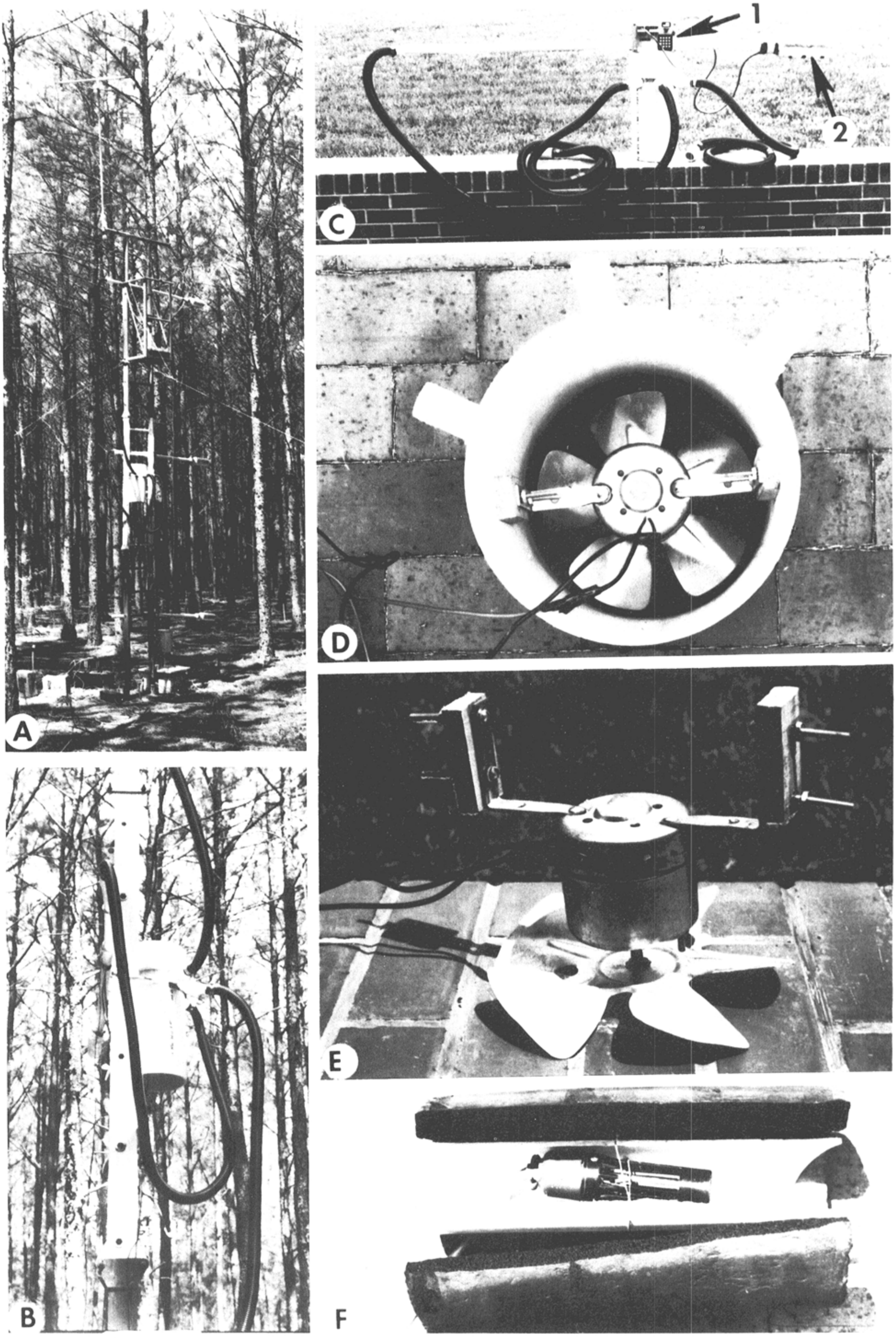

Fig. 1. Aspiration system for meteorological sensors used in plant epidemiology. **A,** The micrometeorological tower with the aspiration system in operation at three levels. **B,** The motor-driven aspiration system with attached sump pump hoses mounted on the tower. **C,** The complete aspiration system for one level. Arrow 1 indicates the Campbell CR-21 Micrologger. Arrow 2 indicates an aspirated, solar radiation-shielded sensor. **D,** The motor mounted inside the 20.3-cm (8-inch) ID PVC pipe viewed from the bottom. **E,** The motor mounting system. **F,** A cutaway view of the shielded relative humidity sensor.

two 5.2-m-tall micrometeorological towers (Fig. 1A). Measurement systems were mounted at 1.0, 3.1, and 5.2 m above ground level. Temperature and RH data were collected from instruments on the towers.

The sensor mountings. The meteorological sensing elements used were the standard ones supplied with the Campbell CR-21 Micrologger. Temperature is sensed with a Fenwal Electronics Model UUT51J1 thermistor. The RH sensor system is composed of a Phys-Chemical Research model PCRC-11 ± 1% deviation RH sensor (Phys-Chemical Research Corp., 36 W. 20th St., New York, NY 10011) and a Fenwal UUT51J1 thermistor (Fenwal Inc., 400 Main St., Ashland, MA 01721) for RH probe temperature compensation.

To house the thermistor and the RH probe, which is about 3.8 cm in diameter, a 5.1-cm (2-inch) inside-diameter (ID) PVC (polyvinylchloride) pipe was used (Fig. 1C and F). If smaller sensors are used, a smaller diameter PVC pipe is recommended to reduce the solid angle of view subtended by the open ends of the radiation shield and thus reduce the amount of sensor exposure to reflected radiation. The PVC pipe that housed the sensors was 30 cm long. The sensor housing section of PVC pipe was joined with a PVC coupling to a 3.2-cm (1.25-inch) ID PVC pipe approximately 1.5 m long (Fig. 1C). This section of pipe was attached to the micrometeorological tower with "U" bolts. The radiation shield was oriented northward and tilted slightly downward to help prevent solar radiation from entering the open end. Couplings were used to join 3.2 cm (1.25 inch) diameter sump pump hose to the end of the 3.2-cm (1.25 inch) ID PVC pipe. The other end of the hose was attached to the 20.3-cm (8-inch) ID PVC pipe housing the motor which ran the aspirating system (Fig. 1B).

Radiation shielding. Radiation shielding (Fig. 1C and F) was provided in two ways. First, the 5.1-cm (2-inch) PVC pipe which housed each sensor was wrapped with 1.9-cm (0.75-inch) thick Rubatex R-180-FS tubing insulation (Rubatex Corporation, Bedford, VA 24523) which is made of closed-cell rubber material. The material is water resistant on the outside and inside surfaces, but not on the cut ends. These were made water resistant by applying Rubatex 373 blue adhesive to each cut end. Additional weather protection can be obtained by coating the tubing with Rubatex Coating 374.

The 1.9-cm (0.75-inch) insulation was covered with standard aluminum foil to provide a highly reflective surface. Aluminum foil has a very low absorptivity (less than 0.05) at all wavelengths. While aluminum foil is convenient to use, inexpensive, and easy to find, it is not the best overall shielding material because of its radiation properties. Fuchs and Tanner (2) recommended that the top side of the upper radiation shield be covered with aluminized Mylar. Mylar is considerably more expensive; however, it has low absorptivity for shortwave radiation and high emissivity for longwave radiation. Thus, the shortwave energy absorbed from the sun is efficiently radiated from the surface as longwave radiation. The bottom surface of the shield will be exposed to reflected shortwave radiation and to the longwave radiation emitted mainly from the forest floor. Thus, it is desirable to use a material with low absorptivity (which implies low emissivity) for both shortwave and longwave radiation. Aluminum foil is ideal for this surface. In the present work, the sensors were located well below a pine canopy. Thus, their exposure to shortwave radiation was of relatively short duration and, as a result, aluminum foil was judged to be a good overall shielding material. Foil also would be the best material to use if all the data were collected at night.

The sensors were suspended in the PVC pipe by a fine wire inserted through a small hole on each side of the pipe. The wire was tied off around the PVC pipe in such a way that the Rubatex insulation was also around the wire (Fig. 1F).

To keep the effects of the solid angle of view subtended by the open end of the shield as small as possible, the sensors were recessed in the shield system to a distance of about four times the tube diameter (3).

Fritchen and Gay (1) point out that the sensor-housing tube should be made of a low thermal conductivity, low emissivity material to prevent unwanted heat transfer to the sensor. PVC has a low thermal conductivity; however, no data on its emissivity were available.

The motor housing section. The central item in the aspiration system is the electric fan motor (Dayton model No. 2M272 Dayton Electric Manufacturing Co., Chicago, IL 60648). The motor is ~7.6 cm in diameter and has a 0.64-cm (0.25-inch)-diameter shaft. It is powered by a 12-V DC battery, operates at 2,350 RPM, and develops 0.0286 HP. The motor was mounted on "L" brackets inside a 20.3-cm (8-inch) ID PVC pipe (Figs. 1D and E). The PVC housing was 45.0 cm long. Holes 5.1-cm (2-inch) in diameter were drilled into the 20.3-cm (8-inch) PVC pipe to accomodate the sump pump hose. The hose was connected to the 20.3-cm (8-inch) PVC pipe with PVC couplings that were sealed to the pipe with PVC cement. The three holes were drilled far enough away from the top of the 20.3-cm (8-inch) PVC pipe to allow a PVC cap to be attached to the top with PVC cement.

The fan, which is mounted on the motor shaft, is made of stamped aluminum and is 17.8-cm (7-inches) in diameter. The five blades are aligned in such a way that the system draws air from the sensors toward the motor. The air is pulled through the hose coming from the instruments on the tower, passes over the motor (which helps cool it), and is expelled from the bottom of the 20.3-cm (8-inch) PVC pipe.

In the present work the 20.3-cm (8-inch) PVC pipe was mounted about halfway up the tower and away from the sensing elements (Fig. 1B). Hot-wire anemometer readings just inside the open end of the PVC pipe indicated that the aspiration system was drawing air past the meteorological sensors at about 2 $m \cdot s^{-1}$.

Aspiration system experiments. Each researcher must decide whether aspiration of environmental sensors is required as a part of a field experiment. In the present case, aspiration was required because wind speeds in the forest were too low to make natural ventilation effective. This is especially true in the early morning hours when temperatures are often lowest and relative humidities highest; a critical period in the plant infection process for many pathogens.

To estimate the effect that aspiration can have, two experiments were performed. The CR-21 data logger was programmed to scan the sensors every 10 sec and to average the readings collected during a 5-min period. All data that were collected on both systems were compared with data collected using a portable battery-powered aspirated psychrometer. The aspirated psychrometer data were used to represent "true" ambient conditions. Results of field tests had indicated no significant differences between the psychrometer data and those obtained with the aspirated system. The aspiration of the psychrometer helps to provide a constant rate of ventilation and improves observational accuracy. Measurement accuracy for temperature is ± 0.15 C and for relative humidity ± 3% RH.

In addition, laboratory experiments were conducted to test the accuracy of the tower sensors, to examine variations in readings from sensor to sensor on the same CR-21 unit (assuming that any given sensor would read the same from channel to channel on a given CR-21 unit), and to examine variations from one CR-21 unit to the next when the same sensors were used. The results indicated that differences of temperature >0.1 C between thermistors indicate real temperature differences, and that individual thermistors are accurate to within about ± 0.1 C. For the RH sensors these numbers are 1% RH and ± 3% RH, respectively. During the field experiments, it was found that there were no real differences between the reading from a given level on the two towers provided both towers were either aspirated or unaspirated. One experiment was designed to eliminate even these minor differences.

In the first experiment, each of the environment towers was wired with a thermistor at the 1.0-m level, a RH probe at the 3.1-m level and a thermistor at the 5.2-m level. The aspiration system on Tower II was powered while the Tower I system remained unaspirated. All sensors were monitored every 5 min by the CR-21 micrologger and differences of comparable sensors at identical elevations noted over a 3-day period. In the second experiment, the same tower was used for both the aspirated and nonaspirated portion of the study. After data from the unaspirated system were

TABLE 1. Performance of an aspirated instrumentation system designed for use in plant epidemiology. The first aspiration experiment (12–13 April 1982)

		Tower I (nonaspirated)			Tower II (aspirated)		
Date/hour	Parameter[a]	1.0 m	3.1 m	5.2 m	1.0 m	3.1 m	5.2 m
12/1000	Temp	14.8	14.5	14.4	15.5	15.1	14.9
	RH		93.6			87.1	
	vp		15.4			14.9	
12/1300	Temp	18.5	18.3	17.9	17.7	17.6	17.3
	RH		88.4			70.3	
	vp		18.6			14.1	
12/2100	Temp	14.9	15.1	15.3	14.3	14.6	14.6
	RH		59.3			66.8	
	vp		10.2			11.1	
13/0200	Temp	13.3	13.1	13.0	13.2	13.3	13.4
	RH		71.2			73.5	
	vp		10.7			11.2	

[a] Abbreviations: Temp = temperature (C); RH = relative humidity (%); and vp = vapor pressure (millibars).

TABLE 2. Performance of an aspirated instrumentation system designed for use in plant epidemiology. The second aspiration experiment (3 and 17 May 1982)

		Nonaspirated sensor		Aspirated sensor	
Date/hour	Parameter[a]	1.0 m	3.1 m	1.0 m	3.1 m
3/0930	Temp	14.1	14.2	15.6	15.4
	RH		97.2		83.7
	vp		15.7		14.6
3/1100	Temp	18.9	18.7	17.9	18.1
	RH		77.2		59.8
	vp		16.6		12.4
17/0945	Temp	16.7	17.0	18.9	18.8
	RH		83.7		71.2
	vp		16.2		15.4
17/1115	Temp	22.5	23.0	19.7	20.1
	RH		65.2		46.3
	vp		18.3		10.9

[a] Abbreviations: Temp = temperature (C); RH = relative humidity (%); and vp = vapor pressure (millibars).

collected, the tower aspirated system was activated and another set of readings were taken after sufficient time (about 5 min) had been allowed for the sensors to come into equilibrium with ambient conditions. After this reading was taken, the aspiration system was turned off.

RESULTS AND DISCUSSION

Representative results from the first field test are shown in Table 1. While spatial variation in sensor readings are not being emphasized in this paper, the vertical variation in temperature should be noted. At 1000 hours, temperatures were higher and RH was lower in the aspirated system than in the unaspirated system. Sensor temperature change in the nonaspirated system is dominated by the radiative term in the basic energy budget equation. Thus, heating of the sensor is slowed as a result of the insulating properties of the shielding system, and therefore does not indicate ambient air temperature at any given time. For the aspirated system, convective as well as radiative heat transfer processes must be considered in arriving at sensor temperature. The convective heat transfer which arises because of aspiration ensures that the temperature sensor is rapidly brought into thermal equilibrium with ambient air.

The RH depends on both the actual vapor pressure and the saturation vapor pressure which is a function of temperature only. Thus, if the actual vapor pressure is the same in both systems and RH is different, this difference is a result of temperature differences. At 1000 hours, both the actual vapor pressure and RH are slightly lower in the aspirated system.

By 1300 hours, the solar elevation angle is quite high resulting in a significant radiative load on the measurement system. The result is temperatures well above ambient in the nonaspirated system while the aspirated sensor reflects ambient conditions. Both the actual vapor pressure and the RH were significantly lower for the aspirated system. The high vapor pressure in the nonaspirated system is the main factor in accounting for the higher RH in this system. This higher vapor pressure could be the result of the evaporation of condensation water which was deposited inside the unaspirated system during the morning hours. The delay in evaporation from the interior surface could result from the thermal lag in the nonaspirated system. Additional tests would need to be conducted to fully understand the observed variations in vapor pressure. Liquid water deposited on either sensor can lead to erroneous readings. After 1300 hours, the diffusion of the water vapor out of the open end of the radiation shield along a vapor pressure gradient and condensation are most likely responsible for the reduction in vapor pressure by 2100 hours.

At night, the temporal changes in net radiation within the forest canopy are both smaller in magnitude and occur more slowly than do daytime changes in net radiation. As a consequence, even the unaspirated system will tend to come into thermal equilibrium with ambient conditions, as shown at 2100 and 0200 hours.

By 2100 hours, temperatures in the nonaspirated system were still somewhat higher than in the aspirated system. The solar-dominated radiation loads of the daylight hours were gone. Since sunset, both systems had been slowly coming into radiative equilibrium with the ambient surroundings through the exchange of longwave radiation. There were no significant differences in temperature by 0200 hours. The same can also be said for the RH and vapor pressure values.

The daytime differences between the nonaspirated and aspirated systems would be substantially greater if the system were exposed to more hours of direct sunshine. This would certainly be the case if the experiment were done over crops instead of within a forest canopy.

Table 2 shows the results of the experiment using a single tower to compare aspirated and unaspirated readings. The results are in close agreement with those found in Table 1. All aspirated sensor readings were insignificantly different from the reference aspirated psychrometer readings, while unaspirated sensor readings deviated significantly. A more satisfactory test would have been a comparison between a properly designed natural ventilation system and the shielded aspiration system presented here. For forest meteorology research conducted below canopy level, the natural ventilation system is not adequate; consequently, an aspiration system was employed from the start in the present work.

Use of the aspiration system described herein should provide epidemiological investigators with an accurate data base for modeling and for understanding the complex relationships between the environment and plant diseases.

Cost. The approximate cost to set up a three-sensor aspiration system was $70, not including the cost of the tower, the 12-V batteries to run the motor, or the CR-21 data logger.

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