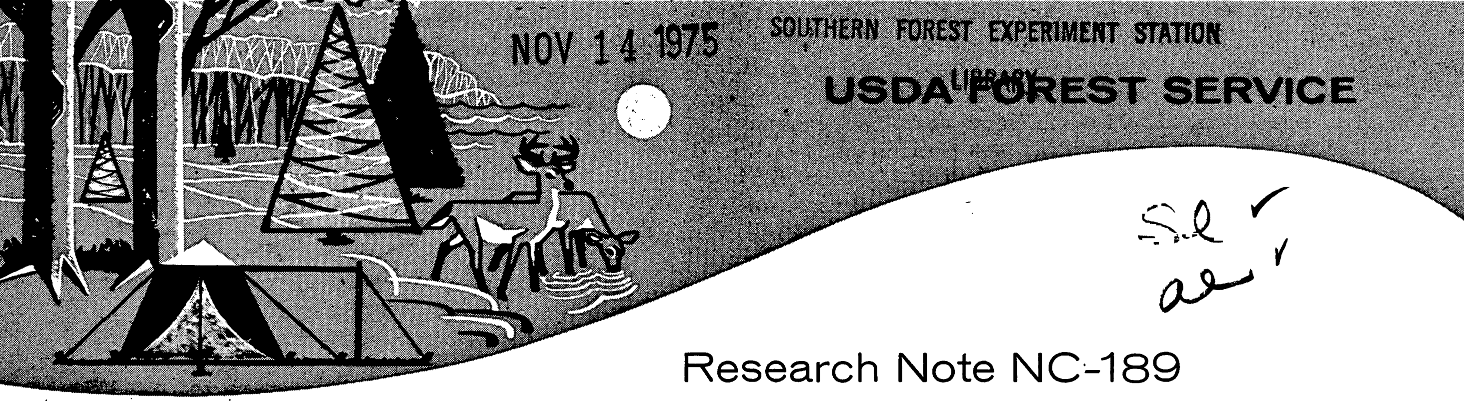

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A CONTROLLED ENVIRONMENT SYSTEM FOR MEASURING PLANT-ATMOSPHERE GAS EXCHANGE

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ABSTRACT.--Describes an inexpensive, efficient system for measuring plant-atmosphere gas exchange. Designed to measure transpiration from potted tree seedlings, it is readily adaptable for measuring other gas exchanges or gas exchange by plant parts. Light level, air and root temperature can be precisely controlled at minimum cost.

OXFORD: 161.2/.3--015.7. KEY WORDS: transpiration, instrumentation, experimental equipment, root temperature regulation, air temperature regulation, plant physiology.

The literature, which contains numerous descriptions of experimental systems for the measurement of gas exchange by plants, has been recently reviewed by Jarvis *et al.*[1] Although the general principles remain much the same, each system varies with the imagination and purpose of the investigator and the availability of equipment, supplies, and funds. Future investigators will doubtless develop individual systems determined by the above constraints rather than construct a replica of a previously designed system. This description is offered in hopes that some of its features might appeal to future investigators and stimulate improvement in the methodology of measuring plant-atmosphere gas exchange.

This system was designed primarily to measure transpiration from individual potted tree seedlings. Sections are, however, transportable and adaptable to measuring gaseous exchange from a variety of vegetation types. It employs the gaseometric method of gas exchange determination, in which the plant is enclosed and the water vapor loss determined by atmospheric gas analysis. The system is open, with gas exchange determined by difference between inlet and outlet gas streams (fig. 1), rather than by recirculating the enclosed atmosphere and noting its change over time, as in the closed type. The numbers in the text refer to figure 1.

The humidifier section receives approximately 80 lb/in.^{2} laboratory bench air that is routed through an oil trap (1) and two pressure regulators (2) before entering a safety backflow bottle at 10 lb/in.^{2} The air then enters the first humidifying bottle (3) that is maintained at room temperature and serves to increase the dewpoint of the airstream to nearly room temperature under most conditions. However, as the air supply for the air compressor is primarily outside air, and as we experience extreme winter cold, the dewpoint of the air supply is sometimes below -30° C. Under these conditions the first humidifying bottle

[1] *P. G. Jarvis and J. Catsky. General principles of gasometric methods and the main aspects of installation design.* In *Sestak, 2. Plant photosynthetic production. Manual of methods. J. Catksy and P. G. Jarvis (eds.). 818 p. The Hague. Dr W. Junk N. V. Publishers. 1971.*

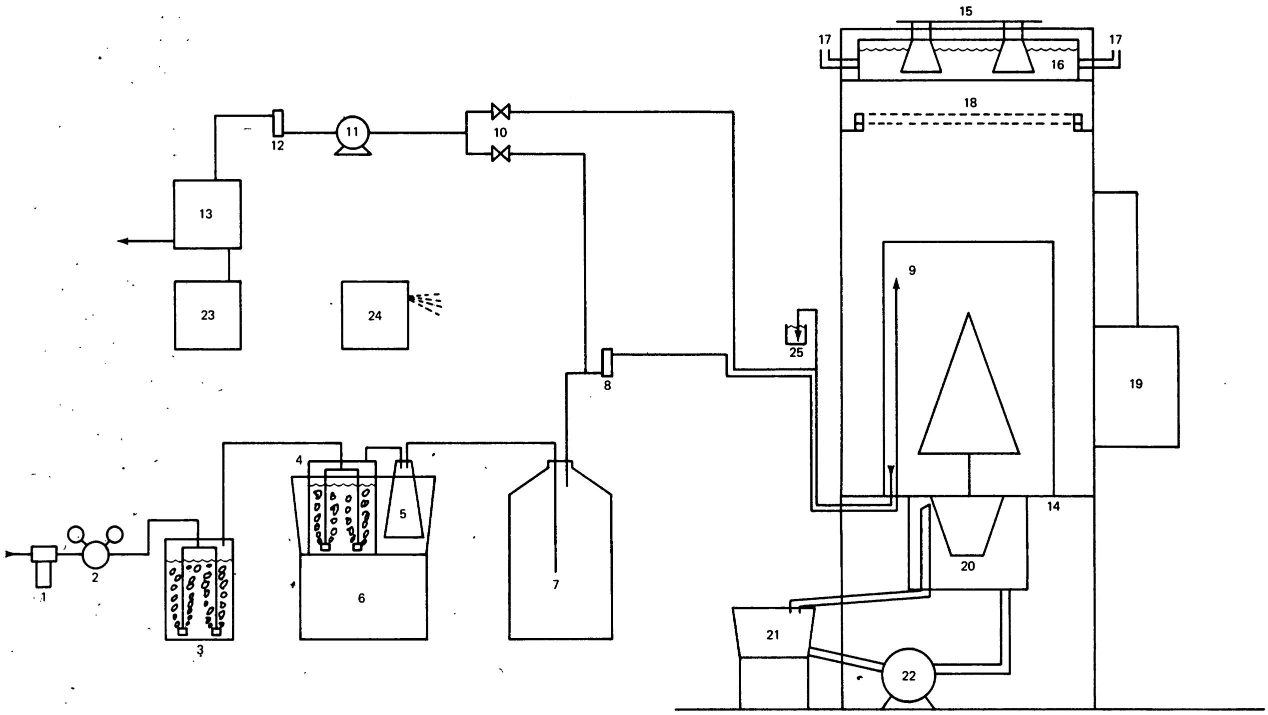

Figure 1.--*Diagrams of air flow system components and plant enclosure affiliated systems. (1) oil trap, (2) pressure regulators, (3) first humidifying bottle, (4) second humidifying bottle, (5) condensing flask, (6) juice cooler-water bath, (7) reservoir jug, (8) regulating flow meter, (9) plant enclosure, (10) solenoid valves, (11) vacuum pump, (12) regulating flow meter, (13) dewpoint hygrometer, (14) wood chamber-base, (15) light bank, (16) circulating water bath, (17) connections to water bath heat exchanger, (18) light filters, (19) air-conditioner, (20) root water bath, (21) root temperature juice cooler, (22) circulating pump, (23) hygrometer recorder, (24) thermocouple recorder, (25) exhaust airstream water seal.*

is necessary to achieve the desired dewpoint; it also removes any oil vapor not removed by the oil trap.

The airstream then enters the second humidifying bottle (4) and the condensing safety bottle (5), both located in a controlled-temperature water bath (6). Normally, these bottles serve as dehumidifiers, reducing the dewpoint of the air from the first humidifying bottle to the temperature of the water bath. I have found that the humidifying-dehumidifying cycle results in a more constant and controllable dewpoint than just a single humidifying step. Both humidifying bottles consist of 1-gal jars three-fourths full of water. Air is bubbled through the water by four airstones of the type used in home aquariums. Aquarium-type "tees" and tubing are used to make the necessary connections. The water bath is a standard, cafeteria-type fruit-juice cooler and dispenser. It contains a reservoir, refrigeration unit, adjustable thermostat, and circulating pump. From the safety condensing bottle, the air enters a 6-1/2 gal glass jug (7) that serves as a reservoir and smooths out any pressure and dewpoint variations before the air enters the plant enclosure.

The humidifying system supplies air over a wide range of dewpoints with a precision of ± 0.2°C, as determined by the temperature of the water bath. I usually maintain a dewpoint of 2°C, but dewpoints down to -8°C may be obtained by adding antifreeze to the water bath. Dewpoints above the ambient could be obtained by heating the water bath.

The plant chamber (9) is built of 6 mm Plexiglas, measures 31.6 by 31.6 by 70.0 cm inside, with a volume of 70 l. A small d.c. fan is connected to a variable power supply to regulate speed and is attached to the top of the chamber to provide internal mixing. I generally maintain an airflow of 20 l/min through this chamber, providing air turnover time of 3.33 min.

The chamber is sealed with silicon grease to a wood base (14), painted to prevent moisture exchange. The chamber base is mounted in a standard instrument mounting rack, with a light bank (15) consisting of four 150-watt incandescent spot lamps submerged in a Plexiglas water bath mounted on the top of the rack. Initially, tapwater was run through the water bath and down the drain; however, problems were encountered as air bubbles formed and coated the bulbs and the Plexiglas. The problem was solved by circulating water between the water bath and a small radiator, or heat exchanger, with a circulating pump. The heat exchanger is placed in a plastic tub in a sink, with cold water running through the tub. If the circulating water is first warmed, then cooled, it is sufficiently degassed to prevent subsequent air bubble formation. The water bath and the heat exchanger are connected with standard 1/2-in. plastic garden hose.

Light intensity is regulated by filters (18) inserted in a frame below the water bath. The filters were constructed by stretching nylon window screening over wood frames. With no filters, full light intensity in the chamber at plant height is 2,400 fc. With one, two, and three filters in place, light intensities are 1,600, 830, and 510 fc, respectively. The corresponding energy flux values for none to four filters, as measured with a Kipps solarimeter, are 0.68, 0.42, 0.26, and 0.16 langleys/min. These values can be varied somewhat by regulating the distance between the light source and the chamber. The above values were determined when the light source was 0.8 m above the plant.

The sides of the instrument rack are enclosed with 3/4-in. chipboard from the chamber base to the bottom of the light bank water bath. This enclosure leaves an approximate 25-cm airspace around the plant chamber. The enclosure is hinged on two sides and is modified on the third side to accommodate an 8,000 Btu room air-conditioner (19), which circulates air around the plant chamber. The air-conditioner internal thermostat was disconnected and a homemade solid-state thermostat substituted. The temperature-sensing element of this thermostat is a thermistor, fed through the chamber base and located within the plant chamber. Internal plant-chamber temperatures ranging from 4° to 27°C ± 0.3°C are readily obtained with this system, under full light.

To change temperature more rapidly in the plant environment, a 0.05-mm polyethylene bag is substituted for the thicker-walled Plexiglas chamber. The bag is secured to the chamber base by a wood frame that is bolted down. This bag has the added advantage of being able to adjust the enclosed volume to conform to the enclosed plant material and thus obtain a more rapid measure of plant response.

Use of polyethylene rather than Plexiglas for the enclosure also alters the radiant energy regime. Measurements with a Kipps Solarimeter and an all-wave radiometer[2] showed both an increase in the total radiation and a greater percent of short-wave radiation (0.3 to 3.0 μ) transmitted by the polyethylene enclosure (table 1). Although part of this difference may be attributed to different transmissivities of the two materials, most of the difference appears to be due to the geometrics of the two enclosures. When the polyethylene film was stretched tautly and held perpendicularly to the light-radiometer axis, values comparable to those for the Plexiglas were obtained. This suggests that the differences shown in table 1 are largely due to the rigid Plexiglas chamber top presenting a more reflective surface than the semispherical inflated polyethylene bag.

Root temperatures are controlled by lowering the pot, sealed in a plastic bag,

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[2] *James M. Brown. Economical conversion of a miniature net radiometer to an all-wave hemispheric radiometer. USDA For. Serv. Res. Note NC-123, 2 p. North Cent. For. Exp. Stn., St. Paul, Minn. 1971.*

Table 1.--*Comparative radiant energy within the Plexiglas and polyethylene enclosures, 0.8 m below light source*
(In langleys/min)

Enclosure	All-wave	Short-wave	Short-wave / All-wave
No enclosure	1.027	0.765	0.75
Polyethylene	1.020	.765	.75
Plexiglas	0.979	.680	.69

into a water bath mounted in the chamber base. This water bath consists of an insulated, 2-gal can (20), into which a water-antifreeze mixture is pumped from another modified juice cooler (21). Fluid level in the water bath is regulated by a standpipe arrangement and the coolant returns to the juice cooler by gravity flow. The attached lid of the can forms a portion of the chamber base, and when a pot is placed in a gasketed opening in the lid, both the water bath and the pot soil are sealed vapor tight. The internal thermostat of the juice cooler refrigeration unit has been disconnected and a homemade thermostat substituted to control the temperature of the circulating coolant. This system provides root temperatures from -5° to 20°C ± 0.2°C.

Air from the humidifying system is transferred through 1/4-in. polyethylene tubing that passes through the chamber base into the plant enclosure. The outlet airstream is via a length of similar tubing, also inserted through the chamber base, and exhausted to the atmosphere through a water seal to achieve a slight (approximately 5 mm) positive pressure within the plant enclosure.

Gas samples are alternately withdrawn from the inlet and outlet air lines by an automatic sampling system consisting of a vacuum pump (11), can timer, and two solenoid valves (10), and passed through a thermo-electric dewpoint hydrometer (13). The vacuum pump is a vibrating diaphram-type home aquarium pump, modified to provide a single inlet point and sealed to prevent leakage. Drying elements and CO_2 analyzer could be connected in series to the airstream exiting from the hygrometer.

The hygrometer recorder output is connected to an adjustable range, adjustable zero, strip-chart recorder that is calibrated to include only that portion of the hygrometer range that is of interest. In normal operation a 25°C span is recorded on the 8.75-in. chart, allowing dewpoints to be readily determined to 0.1°C. Inlet and outlet dewpoints are tabulated, converted to a weight/volume/time basis, and water vapor addition to the airstream determined.

Pot soil, air, needle, and water bath temperatures are measured with copper-constantan thermocouples, recorded on a second strip-chart recorder, and tabulated.

The incorporation of nonspecialized equipment made this system relatively inexpensive to construct. Such items as the juice coolers, instrument racks, etc., can often be obtained as used or surplus equipment and other items locally available can be adapted for use.

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