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EXTENT OF TEMPERATURE FLUCTUATIONS ON SUBSTRATES IN THE GREENHOUSE[1,2]

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Studies in mineral nutrition, with *Marchantia polymorpha* as an experimental plant, are usually conducted with glass cloth (Fiberglas) as the substrate; but quartz sand, vermiculite, and soil are also employed. The temperature characteristics of the surface of these substances when supporting a growth of this liverwort have not been investigated previously. This report contributes to the knowledge of temperatures prevailing under the growing tips of plants of *Marchantia* established in a greenhouse on four types of substrates.

Materials and Methods

With the development of the Abbott-ONR recorder (Voth, unpublished data), it has become relatively easy to detect temperature changes on and in plants and in a variety of environments by using a probe type of thermistor. A change in temperature in the tip of this unit affects its electrical resistance and the impulse is carried by wire cable to an Esterline-Angus milliammeter where a battery-operated, electronic circuit translates changes in thermistor resistance into movements of a recording pen. A spring drive propels not only the paper chart upon which the inked record is inscribed but also regulates the recording from each thermistor in sequence. The present model of the recording device employs five thermistors and a reference recording which serves as a standard, enabling thermistor recordings to be converted into values corresponding to the scale of a centigrade thermometer. For a specified station the resistance values are recorded for 10 minutes by the pen in the milliammeter, followed by recordings of the other stations for the remainder of the hour. A rapid cycle of one minute is also possible, each thermistor recording for only 10 seconds.

Plants in their respective containers were placed a few inches apart near the edge of a greenhouse table at a height of 30 inches from the floor (fig. 1). With the exception of number 3, the sensitive bead of each thermistor was placed under one of the terminal lobes of a plant of *Marchantia*. Only station 2 supported several plants; all others possessed a single several-lobed plant which was established a few days before the experiment was begun.

The five thermistors were located as follows (fig. 1):

1. On loam soil in a glazed pot with side drain, 3½ inches in diameter, 8 inches deep.
2. On vermiculite in a red bulb pan, 8 inches in diameter, 5 inches deep.

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[2] The development and construction of the Abbott-ONR Recorder used in this research was financed by a grant from the Office of Naval Research in 1951 (Project No. Nonr-339[00]).

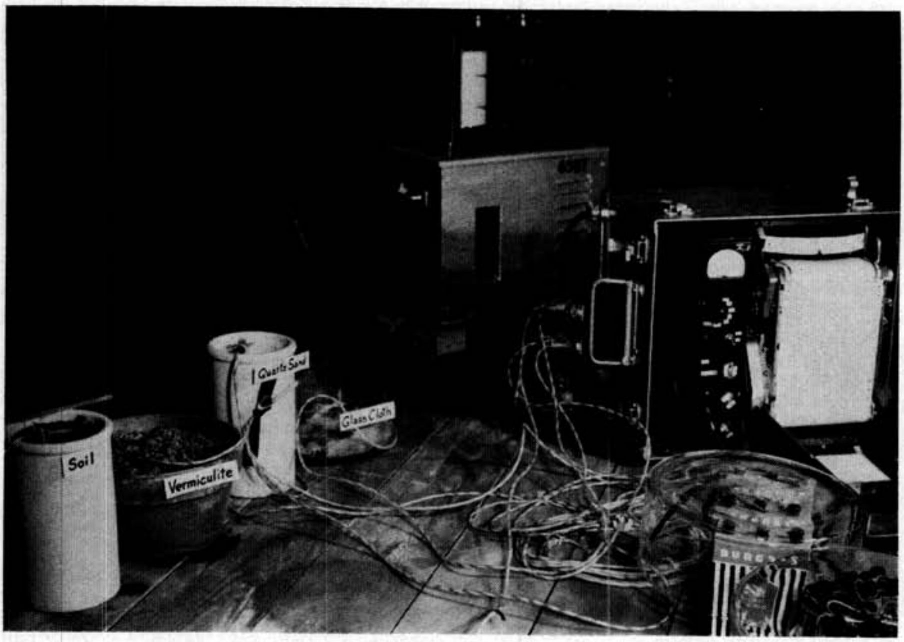


FIG. 1.—At left, four culture units on which plants of *Marchantia* are established. Four probe thermistors, located under plants or in air, are connected by cable to Abbott-ONR recorder at right. Hygrothermograph with housing is in middle rear.

3. In air, attached to the north side of the next station, about 5 inches above the table top.
4. On quartz sand in a glazed pot, as in No. 1.
5. On glass cloth (Fiberglas) in an open moist chamber, 9½ inches in diameter, 3 inches deep (1). A dilute nutrient solution was supplied to this plant only at the beginning of the experiment. About 150 ml. of liquid was maintained throughout this trial.

Plants were watered with tap water at irregular intervals and the floor of the greenhouse was sprinkled with a hose at approximately 8:30 A.M. and 4:00 P.M. every day. Recordings were secured from February 4 to 16, 1954, but detailed data are presented only for a 31-hour period, February 14 to 16.

RESULTS

The period considered in detail was characterized by mild weather. Maximum and minimum temperatures on February 15 were identical at Loop and University stations of the Weather Bureau in Chicago—68° and 39° F. (20.0° and 3.9° C.), respectively (Weather Bureau, Feb., 1954). This is the greatest daily range recorded at these two stations during the first half of February. Prevailing winds were south-southwest for the first 18 hours and north-northeast thereafter. Velocities averaged slightly more than 17 miles per hour, with a high of 24 and lows of about 15 m.p.h. Rain fell for about 13 hours on February 15-16, in the only thunderstorm of the month. Relative humidities were high.

Greenhouse temperatures ranged from 77.0° to 61.0° F. (25° to 16° C.) on February 15; relative humidities ranged from 94 to 72%. Steam heat was available when outside temperatures fell below about 45° F. In contrast to the large range in outside temperatures the greenhouse temperatures on this day remained in a restricted range. On other days of this experiment fluctuations in temperature and humidity in the greenhouse were much greater than on February 15.

Graph paper with five squares to the inch was employed to plot temperature values. An interval on the ordinate is a tenth of a degree centigrade; on the abscissa it is a 10-minute recording. A steady temperature for the 10-minute interval is indicated by a short horizontal bar; a rising or declining temperature by a heavy sloping line, indicating the maximum and minimum temperatures of this time interval. The direction of the slope distinguishes increasing from decreasing temperatures. By connecting the temperature values for each station with broken or solid lines on the graph, thermal conditions under the four plants and in the atmosphere of the greenhouse are readily visualized. Figure 2 shows that the ambient temperature of the greenhouse late at night often is one to two degrees higher than that recorded under plants of *Marchantia*. Temperatures are decreasingly lower on soil, quartz sand, glass cloth, and vermiculite. Supplying cold tap water to the plants resulted in temperature declines in all cultures except in the glass cloth unit, indicating that the solution in the glass moist chamber had a temperature lower than the tap water. After watering, temperatures rose or remained essentially constant in all culture units except in the glass dish where a slight decline occurred during the night.

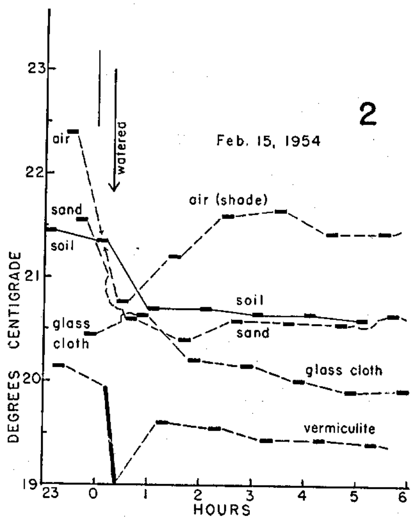
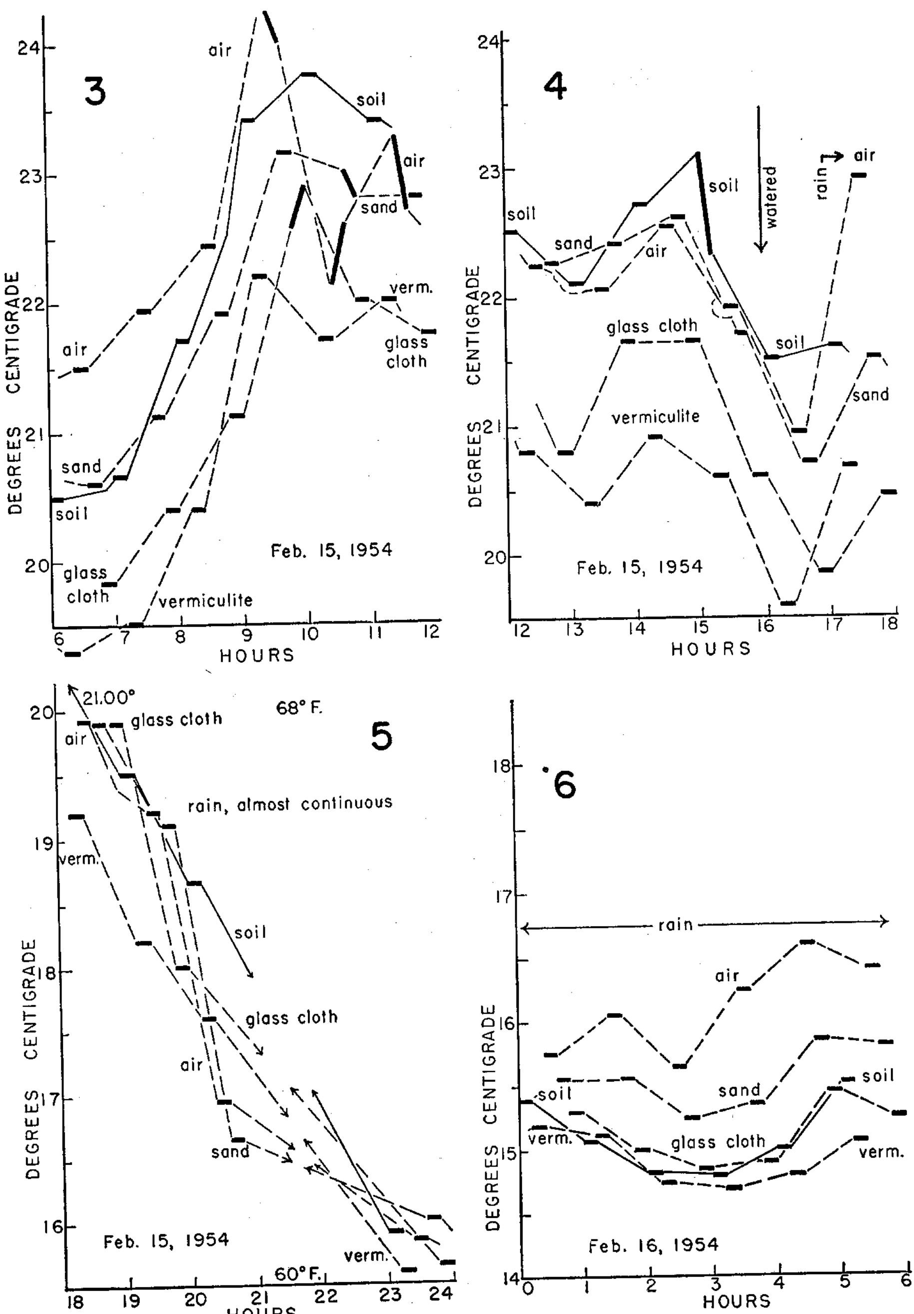


FIG. 2. — Temperatures, shown by heavy bars, as interpreted from recordings secured at five stations in the greenhouse from 11 P.M. Feb. 14 to 6 A.M. Feb. 15, 1954.

In the early hours of morning (fig. 3), sharp rises in temperature occurred in the greenhouse and were correlated with sunshine of intermediate intensity. Room temperatures fluctuated moderately and rose above the values recorded beneath plants of *Marchantia*. Again, temperatures on the substrates followed the pattern observed at night with successively lower values on soil,



FIGS. 3-6.—Temperature readings from five stations shown for 6-hour periods from 6 A.M. Feb. 15 to 6 A.M. Feb. 16, 1954.

quartz sand, glass cloth, and vermiculite.

A brief period of dense cloudiness, possibly abetted by an open ventilator, depressed temperatures in the early afternoon, followed by a rising trend for a few hours (fig. 4). Greenhouse floors were watered at 4:00 P.M. and rain began to fall an hour later. Closing of the ventilators, steam heating in the adjoining room, and drier floors account for the warming at the end of this period. In general, the temperature relations observed earlier were evident during the afternoon also.

With darkness and continuing rain, all temperatures declined precipitously (fig. 5). Even though no recordings are available for two hours near midnight, the pattern is unmistakable. As before, soil tends to be warmer and vermiculite colder than other substrates. Rain, colder weather, and darkness contributed to equalize temperatures so that during several 30-minute periods, thermal differences among all four substrates were as small as 0.1° centigrade.

On February 16, greenhouse temperatures rose slightly in the early morning hours (fig. 6). The rain which fell for approximately 13 hours ceased at 5:50 A.M. The temperature of the plant on sand was higher than that of any other substrate, probably because of the drying effect of steam heat and the small amount of water which adheres to sand grains in the top of the culture. Under the environmental conditions of this period the liquid culture with glass cloth and the surface of the soil unit recorded almost identical temperatures. Vermiculite again possessed the lowest surface temperatures.

Inspection of the charts inscribed by the Abbott-ONR recorder in the early days of the experiment reveals that temperatures on the various substrates followed patterns similar to those reported here. Owing to greater thermal ranges between the various substrates and from hour to hour, the construction of graphs for these days is more difficult.

Discussion

In the experiment no effort was made to correlate the rates of growth of *Marchantia* to the type of substrate employed nor with the temperatures encountered. Availability of nutrients, aeration, longer time required for transplants to become established on soil, and other factors are likely to exert a cumulative effect on cultures of this liverwort which exceeds that of surface temperatures. For this reason areas were not determined nor dry weights measured.

The value of this research should be judged from two viewpoints. First, surfaces of various substrates with scant vegetational cover have their own thermal characteristics. Second, the magnitude of temperature differences as one of the variables in controlled experiments can be evaluated if interval recordings (or continuous recordings) are made while the other data are being accumulated. For plants with deep root systems, thermistors should be placed not only at the surface of the substrate but also deep in the container. It is well known that porosity of substrate, color and surface characteristics of containers, and other factors affect the internal temperatures of plant cultures. In the present experiment it was not possible to secure such readings owing to the small number of thermistors available. An improved model of the recorder is planned in which 25 thermistors or other resistance devices are employed in a single cycle.

High humidities and moderate temperatures permitted *Marchantia* to grow well on quartz sand. Preliminary experients conducted several years ago (Voth and Hamner, 1940) demonstrated that high temperatures and low humidities prevented this liverwort from thriving on sand. Plants with extensive root systems, less affected by surface drying of sand cultures than are bryophytes with only rhizoid systems, are likely to thrive in quartz sand with proper nutrient supplements. This substrate has obvious advantages when strict quality control of the solution is required. As demonstrated in the present investigation, moderate thermal fluctuations and a tendency for surface temperatures to rise following the application of solutions favor the use of quartz sand in nutrient cultures.

Glass cloth as a substrate for liquid cultures is more adapted to plants which can withstand lowered temperatures at night and which have a horizontal habit of growth. *Marchantia* grows well on this medium. The present experiment furnishes data only for greenhouse temperatures during periods of the year when growth of plants is favored by moderate variations of the environment. In early summer and at other times when excessively high temperatures are common, liverworts established on glass cloth have been observed to become necrotic marginally. Readings must be taken with this recorder for periods of temperature extremes before the thermal characteristics of such cultures can be fully evaluated.

Soil is a very useful substrate in many greenhouse experiments, especially when an exact determination of ion supply is not at issue. Temperatures of loam soil favor near-optimum growth of many plants commonly cultivated under glass. Some plants, when grown on rich native soils, exhibit rates of growth, accumulate dry matter, and display a vigor which are difficult or seemingly impossible to attain on other substrates. This observation does not apply to *Marchantia polymorpha* which grows slowly on loam soils in greenhouse culture, but rapidly on glass cloth and vermiculite, provided adequate inorganic nutrients are supplied.

Vermiculite may not be as useful a substrate for the rooting of cuttings and the establishment of seedlings as is commonly thought, owing to a tendency to rapid cooling and maintenance of lowered temperatures following the addition of cold liquids. Adjustment of periods of watering to the warmer times of the day and the use of tepid solutions in replenishing the supply of liquids is an obvious precaution when plants which are sensitive to cold are grown on vermiculite in winter. On the other hand, many bryophytes appear to thrive in a cool environment and probably would benefit by the lower temperatures which characterize the surface of a vermiculite culture.

More than 60 clones of *Marchantia*

polymorpha are currently stocked in the greenhouses of the University of Chicago. Isolates are perpetuated vegetatively by planting a portion of each culture on vermiculite contained in a bulb pan, as used in the present experiment (fig. 1). These plants have survived summer and winter temperatures successfully. In May, the roof panes of the greenhouse are sprayed with a lime mixture which reduces light intensity by more than half. A cheesecloth cover provides additional shade so that the visible radiation reaching the plants is less than 25 percent of the light in untreated rooms. Control of nutrients is also essential in planning cultures for the summer. Vermiculite is well adapted to such control. Details of these methods will be reported elsewhere.

When additional thermistors are available on improved models of the Abbott-ONR recorder, comparisons will be possible between temperatures encountered on the surface and within substrates such as quartz sand and vermiculite. The total volume of substrate as well as the shape, substance, and color of the container must also be tested for thermal characteristics which could well affect the rate of growth of plants. It is to be expected that vermiculite in a porous clay pot will exhibit temperature curves somewhat different from those found in and on the same substance in a glazed, coated, or painted pot of similar design.

Summary

Probe thermistors were placed under the advancing lobes of plants of *Marchantia,* growing on four substrates in a greenhouse. Temperature readings in the form of resistance values were made with the Abbott-ONR recorder.

When outside temperatures in February were moderate, surface temperatures of substrates covered with this liverwort fell into a decreasing series: soil, quartz sand, glass cloth, and vermiculite.

Except for periods of intense insolation, substrate temperatures were lower than the temperature of the surrounding air. Plants growing on soil may have temperatures higher than that of air. Surface temperatures on quartz sand and glass cloth also may exceed air temperatures for brief periods. Temperatures under a liverwort growing on moist vermiculite apparently did not exceed ambient temperatures in the greenhouse.

It is suggested that temperature tolerances of seedlings, cuttings, and cultures of many lower green plants be taken into consideration when greenhouse substrates are selected for experimental or propagating use.

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