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PSYCHROMETRY IN WATER RELATIONS RESEARCH: A REVIEW[1/]

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GRASSLAND BIOME

U.S. International Biological Program

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1/ The Proceedings of the Symposium on Thermocouple Psychrometers: Theory and Applications to Water Relations Research; held March 17-19, 1971, at Utah State University, Logan, Utah.

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ABSTRACT

The Symposium on Thermocouple Psychrometers: Theory and Applications to Water Relations Research was held at Utah State University on March 17, 18, and 19, 1971. The Symposium was co-sponsored by the U.S. International Biological Program, Grassland and Desert Biomes, and the Intermountain Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service. The general themes of the Symposium were the theory and techniques involved in the use of psychrometric instrumentation in water relations research. Some 33 technical papers were presented at the three-day meeting. The Proceedings has been accepted for publication by the Utah Agricultural Experiment Station and will be available late in 1971. The Symposium was dedicated in memory of the late Dr. Sterling A. Taylor, Professor of Soil Physics, Utah State University.

INTRODUCTION

In the late 1940's, Dr. D. C. Spanner, University of London, developed, as part of his doctoral research, a miniature electric psychrometer that would remotely measure the relative vapor pressure of plant material. Subsequent development of the instrument and technique by investigators too numerous to cite led to the widespread use of the thermocouple psychrometer for measuring relative vapor pressure of water in porous media and biological systems. An earlier IBP Grassland Biome technical report (Van Haveren 1971) discusses the theory involved in measuring the energy status of water in soil and plant systems.

In the fall of 1970, Dr. Ray W. Brown and I formulated the idea of a workshop on thermocouple psychrometry to give investigators using or anticipating the use of this method, an opportunity to discuss mutual problems. By December, 1970, we realized that there was more interest in such a meeting than was originally anticipated, and the workshop was expanded to a formal symposium.

The Symposium attracted 176 scientists and graduate students. Nearly all the 50 states were represented as well as eight foreign countries. During the three-day meeting, 33 technical papers were presented. The afternoon of the last day of the Symposium was devoted to instrumentation exhibits and an informal workshop. Nearly a dozen electronics-oriented commercial firms were given the opportunity to display equipment.

DISCUSSION

A Symposium program, collection of abstracts, and list of participants are included as Appendices I, II, and III, respectively. To criticize all the presented papers is not possible at this time, and beyond the scope of this report. The reader is referred to the collection of abstracts in Appendix II.

The Symposium was planned with the following objectives in mind:

(i) To familiarize the participants with the most recent developments in psychrometric methods and instrumentation used in water relations research.

(ii) To present a collection of technical papers authored by knowledgeable scientists concerned with soil, plant, and atmospheric water relations research.

(iii) To attempt to standardize the methodology, instrumentation, terminology, and mathematical symbolism used in describing the energy status of water in the soil-plant-atmosphere system.

In order to meet all these objectives, the Symposium was organized into six sessions covering the theory, design and construction, soil applications, plant applications, and micrometeorological aspects of psychrometric instrumentation. Session VI was an informal workshop. This program enabled soil physicists, plant physiologists, and micrometeorologists to meet under one roof and discuss mutual interests in water relations research.

In the opinion of the co-directors, the first two objectives listed above were met successfully. It was not readily apparent that the third objective was achieved on a formal basis during the meeting. As a result, it was decided the Proceedings should be published as a compendium volume; invited papers not presented at the Symposium will be added to this volume, and the resulting book edited so that the third objective is met. The book, then, will represent a concentrated effort to standardize the concepts involved in water transport through the soil-plant-atmosphere system.

CONCLUSION

The symposium was well received, as measured by the large volume of post-Symposium correspondence received by the co-chairmen indicating appreciation for a fine meeting. I feel that the U.S. IBP, in general, benefitted both by the publicity and by the scientific knowledge that evolved from the Symposium. The grassland and desert biomes profited from the Symposium since it is recognized that water is one of the most important driving forces in these two ecosystems.

LITERATURE CITED

Van Haveren, B. P. 1971. Measurement of the energy status of water in a grassland ecosystem. U.S. IBP Grassland Biome Tech. Rep. No. 76. Colorado State Univ., Fort Collins. 21 p.

APPENDIX I

Symposium on Thermocouple Psychrometers: Theory and Application to Water Relations Research

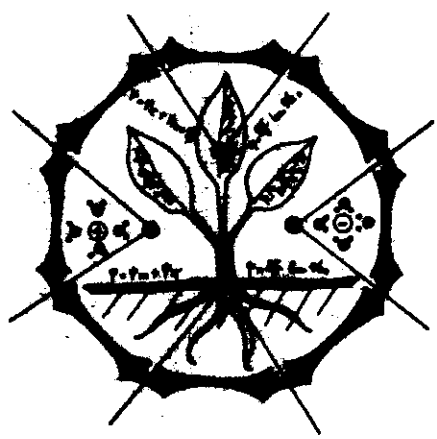
Addendum to Program

Koorevaar, P. and A. R. P. Janse. 1971. Some design criteria for thermocouple psychrometers. (A contribution from the Agricultural University, Wageningen, The Netherlands).

Mohsin, M. A. and B. P. Ghildyal. 1971. Design criteria of thermocouple psychrometers for water potential measurements in plants. (A contribution from the Rajendra Agricultural University, India).

Thurtell, G. 1971. The construction and use of a dewpoint psychrometer for *in situ* measurement of leaf-water potentials. (A contribution from the University of Guelph, Guelph, Ontario, Canada).

Meyn, R. L. and R. S. White. 1971. Calibration of thermocouple psychrometers: A suggested procedure for development of a reliable predictive model. (A contribution from Utah State University, Logan, Utah).



Symposium on Thermocouple Psychrometers:
Theory and Applications To Water Relations Research

utah state university march 17 - 19, 1971

SPONSORED BY

U. S. International Biological Program

in cooperation with

U. S. Department of Agriculture, Forest Service
Intermountain Forest and Range Experiment Station

DIRECTED BY

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Forestry Sciences Laboratory
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SCHEDULE

Tuesday	March 16, 1971. Arrive at Utah State University, Logan, Utah. Limited transportation will be provided from the Salt Lake City International Airport to Logan.
Wednesday	March 17, 1971. Symposium opens at 9:30 a.m. in the Sky Room, University Center Building. Evening social hour and banquet at the Elks Lodge.
Thursday	March 18, 1971. Symposium proceedings continue.
Friday	March 19, 1971. Symposium proceedings continue. Symposium closes at 5:00 p.m. Limited transportation will be provided from Logan to the Salt Lake City International Airport.

REGISTRATION

Participants may register at the office of the Conference and Institute Division, University Center Building, from 12:00 noon to 5:00 p.m. on Tuesday, March 16, and from 8:00 a.m. to 9:30 a.m. on Wednesday, March 17. The registration fee will be $15.

PRESENTATION OF PAPERS

All sessions will be held consecutively in the Sky Room, University Center Building, on the campus of Utah State University. Each presentation will be limited to 20 minutes, followed by a 10 minute discussion. All participants are encouraged to contribute to the discussions.

PROGRAM

Tuesday, March 16

12:00 - 5:00 p.m. Registration: Conference and Institute Division Office, University Center Building.

Wednesday, March 17

8:00 a.m. Registration: Conference and Institute Division Office, University Center Building.

SKY ROOM UNIVERSITY CENTER BUILDING

9:30 a.m. Opening Remarks
Ray W. Brown, Forestry Sciences Laboratory

9:45 a.m. Welcoming Address and Dedication
D. Wynne Thorne, Utah State University

10:00 a.m. Keynote Address: Plants, water, and some other topics; Adventures of a plant physiologist.
Douglas C. Spanner, University of London

10:30 a.m. Break

SESSION I. THEORY OF THERMOCOUPLE PSYCHROMETERS

Moderator: Gaylon S. Campbell, Washington State University

11:00 a.m. Theory of thermocouple psychrometers used to measure plant and soil water potential.
Stephen L. Rawlins, U. S. Salinity Laboratory

11:30 a.m. Use of isopiestic technique in thermocouple psychrometry I. Theory.
John S. Boyer, University of Illinois

12:00 p.m. Lunch

SESSION II. CONSTRUCTION AND DESIGN CRITERIA OF THERMOCOUPLE PSYCHROMETERS

Moderator: Stephen L. Rawlins, U. S. Salinity Laboratory

1:00 p.m. A microwelder for the construction of the thermocouple junction of Peltier thermocouple psychrometers.
William Lopushinsky, Forest Hydrology Laboratory

1:30 p.m. Comparisons of thermocouple psychrometers with and without massive heat sinks.
Gail Bingham, Michael N. Johnson, and E. R. Lemon, Cornell University

2:00 p.m. Vapor sink and thermal gradient effects on psychrometer calibration.
Eric Campbell, Wescor, Inc., Logan, Utah

2:30 p.m. Use of isopiestic technique in thermocouple psychrometry II. Construction.
John S. Boyer University of Illinois

3:00 p.m. Break

3:30 p.m. A thermo-electric transducer for soil-moisture energy measurement.
Irel S. McQueen, U. S. Geological Survey

4:00 p.m. Pulsed thermistor psychrometer for measuring vapor pressure differential.
Joseph H. Kitchen and John L. Thames, University of Arizona

4:30 p.m. A semi-automatic thermocouple psychrometer readout designed for ease and simplicity of measurement.
Howard Schimmelpfennig Kansas State University

6:30 p.m. Social hour and banquet, Elks Lodge.

Thursday, March 18

SESSION II. CONSTRUCTION AND DESIGN CRITERIA OF THERMOCOUPLE PSYCHROMETERS (cont.)
Moderator: Stephen L. Rawlins, U. S. Salinity Laboratory

8:00 a.m. A multichannel technique to study water potential distribution in the root zone under simulated field conditions.
George E. Merva, Michigan State University

8:30 a.m. Automated measurements of water potential and its components using thermocouple psychrometers.
Glenn J. Hoffman J. D. Oster, and S. D. Merrill, U. S. Salinity Laboratory

SESSION III. APPLICATION OF THERMOCOUPLE PSYCHOROMETERS TO DETERMINATIONS OF WATER POTENTIAL IN SOIL AND OTHER MEDIA.
Moderator: R. John Hanks, Utah State University

9:00 a.m. Water potential measurements of soil samples.
Gaylon S. Campbell and Alma M. Wilson, Washington State University

9:30 a.m. Thermocouple psychrometry for the study of water relations of soil microorganisms.
W. R. Gardner, F. N. Dalton, and R. F. Harris, University of Wisconsin

10:00 a.m. Break

10:30 a.m. Application of temperature compensated psychrometers to the measurement of water potential gradients.
Jack J. C. Hsieh, C. G. Enfield, and F. D. Hungate, Battelle Memorial Institute

11:00 a.m. The field use of thermocouple psychrometers in desert soils.
R. T. Moore and M. M. Caldwell, Utah State University

11:30 a.m. Psychrometric measurements under desert conditions.
H. K. Oashu, M. L. Wheeler, and D. D. Evans University of Arizona

12:00 p.m. Lunch

1:00 p.m. Biologic fluid osmolar studies using a thermocouple psychrometer.
DeWitt T. Hunter, Latter Day Saints Hospital

1:30 p.m. Measurements of vapor pressure in snow with thermocouple psychrometers.
Bruce P. Van Haveren, Colorado State University

SESSION IV. APPLICATION OF THERMOCOUPLE PSYCHROMETERS TO DETERMINATIONS OF PLANT WATER POTENTIAL
Moderator: W. R. Gardner, University of Wisconsin

2:00 p.m. Significance of plant water potential components.
Herman H. Wiebe, Utah State University

2:30 p.m. Determination of leaf osmotic potential with Peltier thermocouple psychrometers.
Ray W. Brown, Forestry Sciences Laboratory

3:00 p.m. Break

3:30 p.m. Determination of plant matric potential with thermocouple psychrometers.
Lee Miller Cornell University

4:00 p.m. Use of isopiestic technique in thermocouple psychrometry III. Application to determinations of plant water potential.
John S. Boyer, University of Illinois

4:30 p.m. A temperature compensated leaf psychrometer for *in-situ* measurements of water potential.
C. Calissendorff and W. H. Gardner, Washington State University

Friday, March 19

SESSION IV. APPLICATION OF THERMOCOUPLE PSYCHROMETERS TO DETERMINATIONS OF PLANT WATER POTENTIAL (cont.)
Moderator: W. R. Gardner, University of Wisconsin

8:00 a.m. Germination and emergence of seedlings as affected by soil water potential
Walter T. McDonough, Forestry Sciences Laboratory

8:30 a.m. Growth rates of native grasses and soil water stress as measured with thermocouple psychrometers.
Lee E. Eddleman and Thomas J. Nimlos, University of Montana

SESSION V. APPLICATIONS OF PSYCHROMETRY IN MICROMETEOROLOGY
Moderator: C. B. Tanner, University of Wisconsin

9:00 a.m. Opening remarks on psychrometry in micrometeorological investigations.
C. B. Tanner, University of Wisconsin

9:30 a.m. On the construction and use of ceramic wick thermocouple psychrometers.
L. W. Gay, Oregon State University

10:00 a.m. Break

10:30 a.m. Psychrometric measurements as used for studies of cold air lakes.
Inge Dirmhirn, Utah State University

11:00 a.m. Construction of a thermistor psychrometer for field recording of atmospheric relative humidity.
Bland Z. Richardson, Forestry Sciences Laboratory

11:30 a.m. Closing Remarks
Ray W. Brown, Bruce P. Van Haveren, and Herman H. Wiebe

12:00 p.m. Lunch

SESSION VI. DEMONSTRATIONS OF INSTRUMENTATION AND WORKSHOP
Moderators: Ray W. Brown, Bruce P. Van Haveren, and Herman H. Wiebe

1:00 p.m. Demonstrations of instrumentation, Sky Room.
Brian Cleary, Weyerhaeuser Co., Bland Z. Richardson, Forestry Sciences Laboratory, William Lopushinsky, Forest Hydrology Laboratory, Eric Campbell, Wescor, Inc., Hewlett-Packard Co.

2:00 p.m. Workshop: equipment and instruction will be provided for those interested in learning construction and measuring techniques. The following will be covered:

1. Construction of Peltier thermocouple psychrometers
2. Calibration of Peltier psychrometers
3. Making measurements with Peltier psychrometers, including use of related instrumentation.

3:00 p.m. Break

3:30 p.m. Workshop continued

5:00 p.m. Symposium closes

APPENDIX II

SYMPOSIUM ON THERMOCOUPLE PSYCHROMETERS: THEORY AND APPLICATIONS TO WATER RELATIONS RESEARCH

Utah State University

March 17 - 19, 1971

ABSTRACTS

SESSION I. THEORY OF THERMOCOUPLE PSYCHROMETERS

Moderator: Gaylon S. Campbell

Washington State University

THEORY OF THERMOCOUPLE PSYCHROMETERS USED TO MEASURE PLANT AND SOIL WATER POTENTIAL

S. L. Rawlins

U.S. Salinity Laboratory, Riverside, California

Theory for the thermocouple psychrometer relating the output electromotive force to temperature, pressure, psychrometer geometry, as well as to the water potential of the sample is reviewed. A comparison is made of a governing equation for heat transport in the stagnant air of a thermocouple psychrometer chamber with that for the ventilated psychrometer normally used. The analysis suggests essential design criteria necessary to preclude systematic errors in water potential measurement.

USE OF ISOPIESTIC TECHNIQUE IN THERMOCOUPLE PSYCHROMETRY

J. S. Boyer

University of Illinois, Urbana, Illinois

I. Theory

A technique which employs a null or isopiestic method of matching vapor pressures is described for measuring the water potential of plant

tissue. The method avoids error due to the diffusive resistance of leaf tissue, gives accurate water potentials with plant tissue of known water potential, and can be used to measure error due to diffusive resistance in Spanner and in Richards and Ogata thermocouples. A simple method is described for finding the isopiestic value. Measurements by isopiestic technique indicate that Richards and Ogata determinations may be in error by as much as 20% due to the diffusive resistance of the tissue. Measurements made with the Spanner technique appear to be in error but the errors are more variable and usually less than with the Richards and Ogata technique.

CALIBRATION OF THERMOCOUPLE PSYCHROMETERS: A SUGGESTED PROCEDURE FOR DEVELOPMENT OF A RELIABLE PREDICTIVE MODEL

Richard L. Meyn and Richard S. White

Utah State University, Logan, Utah

One serious limitation of the psychrometric method for evaluating the free energy status of water in the soil-plant-atmosphere system has been the problem of calibration. Psychrometric output of soil psychrometers is both a function of temperature and of water potential. Previously published temperature correction coefficients appear to be inadequate when considering a wide range of soil-water potentials.

This paper will present a procedure for development of a reliable predictive model from calibration data. Water potential as related to temperature, psychrometric output, and an interaction between temperature and psychrometric output will be discussed. For an individual soil psychrometer, a predictive model (with a range of 8 to 26°C and 4.6 to

46.6 bars) has been developed with an r^2 equal to 0.9958 and an ability to predict water potential within ± 1.0 bars or less of the calibration solution potential.

Suggestions will be made for reducing the time necessary for calibrating large numbers of psychrometers while maintaining a high degree of predicability in the resulting calibration equation.

SESSION II. CONSTRUCTION AND DESIGN CRITERIA OF THERMOCOUPLE PSYCHROMETERS

Moderator: Stephen L. Rawlins

U.S. Salinity Laboratory

A MICROWELDER FOR THE CONSTRUCTION OF THERMOCOUPLE JUNCTIONS OF PELTIER THERMOCOUPLE PSYCHROMETERS

William Lopushinsky

Forest Hydrology Laboratory, Wenatchee, Washington

A welding jig is described for making fine wire thermocouples for use in Peltier thermocouple psychrometers. Procedures are described for producing bead-type thermocouples with little or no twisted wire at the junction. Junctions made with the jig produced higher outputs at low water potential than commercially available thermocouples. Thermocouples in which the first contact of the wires occurred at the junction were the most uniform in output.

COMPARISONS OF THERMOCOUPLE PSYCHROMETERS, WITH AND WITHOUT "MASSIVE" HEAT SINKS

Gail E. Bingham, Michael N. Johnson and E. R. Lemon

Cornell University, Ithaca, New York

Current literature pertaining to the construction of thermocouple psychrometers is explicit in explaining the need for and desirability of massive heat sinks at the reference junctions. However, many scientists

continue to construct psychrometers paying little or no attention to this detail. The inclusion of theoretically-sufficient heat sinks in the psychrometer multiplies by several times the bulk, mass and cost of manufacture of the item. Particularly in the design of instruments for *in situ* measurements one is tempted to overlook this detail.

Two types of Peltier thermocouple psychrometers are compared, each using three different heat sinks, having negligible, inadequate and theoretically-sufficient masses. It was shown that when the calibration conditions are duplicated, psychrometers having no appreciable heat sinks provide accurate water potential data. However, for maximum sensitivity over the entire range and linear response over the widest possible range, the theoretically-sufficient heat sinks are necessary. A larger signal at higher potentials, an earlier onset of nonlinearity and lower overall sensitivity are characteristics of little or no heat sink. The inadequate mass case fell between the two extremes. This indicates that some heat sink move closely approximates ideal conditions. A method of cooling is suggested to minimize the no heat sink effect.

VAPOR SINK AND THERMAL GRADIENT EFFECT ON PSYCHROMETER CALIBRATION

Eric C. Campbell

Wescor, Inc., Logan, Utah

Analysis of water potential as it relates to the psychrometer system is described. Some simplifying assumptions are made resulting in two considerations which are used independently in analyzing effects due to thermal gradients and vapor sinks. These considerations are (1) the measurement of water potential at a point in a gaseous volume, and (2) the

average surface water potential of the total interior surface of the psychrometer chamber. Results of experiments based on analysis of these considerations as they relate to specific effects indicate the following:

1. Non-evaporating surface materials that can be used to minimize vapor sink effects include brass, nickel, stainless steel, chrome, teflon, polyethylene and vaseline.

2. Contaminants on the chamber surfaces or on the thermocouple junction have an overwhelming effect on equilibration time and on calibration.

3. Thermal gradient effects can be minimized by placing the non-evaporating surface of the chamber such that its average temperature is the same as that of the evaporating surfaces when the chamber is subjected to thermal gradients.

USE OF ISOPIESTIC TECHNIQUE IN THERMOCOUPLE PSYCHROMETRY

J. S. Boyer

University of Illinois, Urbana, Illinois

II. Construction

Equipment is described for measuring plant water potential by a null or isopiestic technique which consists of finding the vapor pressure of a solution on a thermocouple that matches the vapor pressure of the plant tissue. The equipment involves a thermocouple which can be rapidly inserted and removed from a psychrometer chamber, which in turn is mounted in a constant temperature bath. Since isopiestic technique is employed, electrical circuitry can be kept simple, the system requires little or no calibration, and variability due to sample placement or chamber dimensions is avoided. The equipment is relatively inexpensive and easy to maintain.

DESIGN CRITERIA OF THERMOCOUPLE PSYCHROMETERS FOR WATER POTENTIAL MEASUREMENTS IN PLANTS

M. A. Mohsin

Rajendra Agricultural University, Patna 14, Bihar, India

and

B. P. Ghildyal

U. P. Agricultural University, Pantnagar, Nainital, India

The design problems encountered while assembling a thermocouple psychrometer setup for water potential measurements in plants have been discussed. The theory advocated by Rawlins for the theoretical calculations of the output electromotive force from the psychrometer on the basis of the design parameters, was found to agree fairly well with the experimental results. However, empirical calibration of these instruments seems always essential.

SOME DESIGN CRITERIA OF THERMOCOUPLE PSYCHROMETERS

P. Koorevaar and A. R. P. Janse

Agricultural University, Wageningen, Holland

At first some conclusions are drawn concerning the size of the wires of the thermocouple in relation to that of the psychrometer chamber. A discussion on the cooling current follows. Next the circuitry for the temperature measurement and registration is considered. The exigences concerning a thermostatic bath and its control are dealt with, partly obtained after some practical experiences.

PULSED THERMISTOR PSYCHROMETER FOR MEASURING VAPOR PRESSURE DIFFERENTIAL

Joseph H. Kitchen and John L. Thames

University of Arizona, Tucson, Arizona

A miniature thermistor instrument which easily resolves temperature differences of 0.001°C has been developed for measuring vapor pressure over a wide temperature range. Its response to differential vapor pressure closely matches the response predicted by thermodynamic theory. The instrument consists of: (1) a thermistor probe assembly; (2) circuit for generating a pulse having a duration of 10 to 100 milliseconds; (3) pulse amplitude control circuit which controls the amplitude of the output pulse; and (4) constant current source which maintains one milliamp through the thermistor sensor regardless of its temperature dependent resistance variations. Voltage measurement across the probe is made with an oscilloscope equipped with a differential input amplifier. Use of the instrument for measuring salt front movement in soil during miscible displacement is described.

SEMI-AUTOMATIC THERMOCOUPLE PSYCHROMETER READOUT

Howard Schimmelpfennig

Kansas State University, Manhatten, Kansas

This paper describes the construction and use of a thermocouple psychrometer readout system designed to eliminate operator fatique and peak point ambiguity. Incorporated in the system are input switching,

microvolt meter, cooling timer, peak reader, and thermocouple thermometer. The system can easily be modified to fit a particular application and can be built in a well-equipped laboratory.

A MULTICHANNEL TECHNIQUE TO STUDY WATER POTENTIAL DISTRIBUTION IN THE ROOT ZONE UNDER SIMULATED FIELD CONDITIONS

George E. Merva and N. Kilic

Michigan State University, East Lansing, Michigan

Commercially available components were used to fabricate a controlled environmental unit to simulate field conditions in a repeatable manner for detailed laboratory analysis of environmental effects upon plant physiological response. The simulation unit is described and provides for measurement and control of above- and belowground parameters of temperature, relative humidity and both the actual amount as well as differential rates of production or withdrawal of CO_2. Continuous mass changes of the soil-plant system are obtained through a technique of measuring unbalance of the system up to 450 grams.

The application of the system to investigate water potential distributions in the developing root zone of a kidney bean plant is presented. A 100 liter container is used as the soil environment. Twenty-four thermocouple psychrometers are read automatically by a specially designed cycling device and the output recorded on punched paper tape for computer analysis. The information thus obtained is used for equipotential mappings of water potential distributions in the rooting system of a developing plant.

AUTOMATED MEASUREMENT OF WATER POTENTIAL AND ITS COMPONENTS USING THERMOCOUPLE PSYCHROMETERS

G. J. Hoffman, J. D. Oster and S. D. Merrill

U.S. Salinity Laboratory, Riverside, California

An automatic system to read six Peltier thermocouple psychrometers in about 2 minutes has been built and tested. With a few auxiliary components as many as 150 psychrometers are read in 1 hour and the same psychrometers can be read in 12-minute intervals. The standard deviation for automatically recorded psychrometer calibration outputs is ±0.044 μv, and under actual experimental conditions, the values obtained with the automatic system are as accurate as measurements made manually.

Examples of experimental data taken automatically are also given. Daily soil water potential values in alfalfa field plots through two irrigation cycles are presented along with leaf water and osmotic potentials for three root crops grown under different salinity and relative humidity treatments. The techniques and precautions followed in making these measurements are briefly described.

Two methods for determining soil matric and osmotic potentials are outlined and typical results are presented. One method involves using salinity sensors and the other pressure plate apparatus in conjunction with thermocouple psychrometers.

SESSION III. APPLICATIONS OF THERMOCOUPLE PSYCHROMETERS TO DETERMINATIONS OF WATER POTENTIAL IN SOILS AND OTHER MEDIA

Moderator: R. John Hanks

Utah State University

WATER POTENTIAL MEASUREMENTS ON SOIL SAMPLES

Gaylon S. Campbell and Alma M. Wilson

Washington State University, Pullman, Washington

and USDA-ARS, Pullman, Washington

An important application of thermocouple psychrometry has been measurement of soil water potential. Water potential measurements are generally in the 0 to -50 bar range, but using special techniques measurements to 01000 bars are possible. Applications of both the Richards and the Spanner psychrometers to water potential measurement of soil samples are discussed. Techniques for determining sorption and desorption isotherms of samples are given, and precautions for sample handling are outlined. The effects of temperature and bulk density changes on sample water potential are indicated.

Details of a technique for measuring water potentials to -1000 bars using the Spanner psychrometer are given. The psychrometer is placed in a

multiple sample changer and cooled over a -10 bar KCl solution for 20 minutes. The sample changer is then rotated to bring the thermocouple over the sample, and a reading is taken.

Methods for measuring components of soil water potential are also discussed. The matric and osmotic potentials may be obtained by using a special pressure chamber together with the thermocouple psychrometer. Osmotic and matric potentials may also be inferred by using a salinity sensor in conjunction with the psychrometer.

THERMOCOUPLE PSYCHROMETRY FOR THE STUDY OF WATER RELATIONS OF SOIL MICROORGANISMS

W. R. Gardner F. N. Dalton and R. F. Harris
University of Wisconsin, Madison, Wisconsin

The water relations of soil microorganisms are less well understood quantitatively than those of higher plants. Due to their small size and lack of transpiration, microorganisms are more closely coupled to their environment than higher plants. Artificial substrates such as agar gel have proven much more convenient than soils for the study of such organisms. The thermocouple psychrometer has proven to be the most reliable means of characterizing the water status of such substrates. The psychrometer has also proven to be of value in measuring the osmotic and turgor components of the water potential in cases where cryogenic or other procedures are unreliable.

APPLICATION OF TEMPERATURE COMPENSATED PSYCHROMETERS TO THE MEASUREMENT OF WATER POTENTIAL GRADIENTS

J. J. C. Hsieh, C. G. Enfield, and F. P. Hungate
Battelle Memorial Institute, Richland, Washington

Evaluation of water flux in soil and plant systems requires a knowledge of water potential gradients. Water potential gradients indicate the direction and the magnitude of the driving forces causing water movement under isothermal conditions. In desert environments where conventional neutron and gravimetric techniques have not been satisfactory, psychrometric techniques are useful. Design criteria are discussed for a microwater potential gradient transducer using quick response temperature compensated thermocouple psychrometer which has a zone of influence being less than one millimeter. Soil water potential gradients have been measured on a one dimensional 2 mm grid network in the laboratory. The transducer is particularly useful in studies where high potential gradients are encountered. Field application of the technique appears feasible in both soil and plant systems.

THE FIELD USE OF THERMOCOUPLE PSYCHROMETERS IN DESERT SOILS

R. T. Moore and Martyn M. Caldwell
Utah State University, Logan, Utah

Peltier-type thermocouple psychrometers were used to measure soil moisture depletion within the major root zone by two cold desert shrubs at Curlew Valley in northern Utah. Similar measurements were taken using potted plants in the laboratory.

Water potentials in the field ranged from near field capacity at 15 cm depth and -5 to -15 bars at lower depths in April, to -40 to -70 bars at 15 cm and -70 to -85 bars at lower depths in October. Most *Atriplex confertifolia* plants and some *Eurotia lanata* plants were actively transpiring throughout the entire period.

At depths of 60 cm and greater, soil salinity became a major component of the total soil water potential. At these depths soluble salts exceeded 0.6% during most of the growing season. These salt concentrations frequently lowered the total soil water potential as much as 30 bars when compared to soil samples from shallower depths with the same water content but with negligible salts.

Measurements of soil water potentials by the thermocouple psychrometers corresponded quite well with soil water content and plant water stress determinations.

PSYCHROMETRIC MEASUREMENTS UNDER DESERT CONDITIONS

M. L. Wheeler, H. K. Oashu and D. D. Evans

University of Arizona, Tucson, Arizona

Commercially available temperature compensated thermocouple psychrometers were individually calibrated in the laboratory and found to have an accuracy of +0.5 bars at 25°C. The units were installed at selected depths within a small plot of bare ground at a desert field site. The responses of units at a given depth are sufficiently uniform to justify the assertion that the units are measuring the actual soil moisture potential. The response of units to climatic variables was predictable, in a qualitative

sense. The variability among units at a given depth appears to be least during quasi-stable or drying conditions. Additional units will be installed adjacent to the root systems of desert plants. The units will be utilized to investigate the nature of soil-water uptake by these plants.

BIOLOGIC FLUID OSMOLAR STUDIES USING A THERMOCOUPLE PSYCHROMETER

DeWitt T. Hunter and Eric C. Campbell

Latter Day Saints Hospital, Salt Lake City, Utah

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Numerous disease processes are complicated by serum electrolyte and associated osmolar derangements. Quantitative osmolar studies on serum and/or urine enable the clinician to institute rational replacement therapy. Equipment presently available is slow in operation and rather costly. The Model C-51 Sample Chamber Psychrometer (Wescor) was tested for applicability in biologic fluid osmolar analyses. This apparatus ostensively fulfilled most of the requisites for clinical laboratory utilization. It was compact, simple and rapid in operation, economic in specimen utilization, and competitive in price. The experimental studies included standardization of methodology using primary aqueous solutions and the testing of several hundred normal and patient sera and urine samples. All specimens were tested in parallel by a freezing point depression technique. Normal values, accuracy, precision, and correlative data will be presented.

MEASUREMENTS OF VAPOR PRESSURE IN SNOW WITH THERMOCOUPLE PSYCHROMETERS

B. P. Van Haveren

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The process of snow metamorphism is highly dependent upon the existence of negative vapor pressure gradients within the snowpack. Strong negative gradients result in a transfer of water vapor and redistribution of mass from warmer to colder regions of the snowpack. Thermocouple psychrometers were placed in a mountain snowpack to measure vapor concentrations of the void air. Preliminary results indicate slight undersaturation of the void air in the middle regions of the profile and greater undersaturation in the top 20 centemeters. The significance and possible causes of undersaturated void air in seasonal snowpacks is considered. In addition, the use and calibration of thermocouple psychrometers in temperatures below 0°C is discussed.

SESSION IV. APPLICATIONS OF THERMOCOUPLE PSYCHROMETERS TO DETERMINATIONS OF PLANT WATER POTENTIAL

Moderator: W. R. Gardner

University of Wisconsin

SIGNIFICANCE OF PLANT WATER POTENTIAL COMPONENTS

Herman H. Wiebe

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Decreases in plant water potential are generally accompanied by decreases in growth rates as well as decreases in turgor pressure, and to a lesser degree, by decreases in osmotic potential (solutes become more concentrated and osmotic potential becomes more negative). Although water potential is the factor determining direction of water movement through the soil-plant atmosphere system, the water potential components appear of more direct significance in other processes. Turgor pressure provides the immediate force for cell wall expansion, and also, according to widely held hypotheses, for stomata opening and phloem translocation. The osmotic potential is a function of the solute environment, which is of immediate significance in enzyme function, and consequently, in all biochemical processes within the cell. Characterization of plant water status should preferably include osmotic potential as well as water potential determinations.

DETERMINATION OF LEAF OSMOTIC POTENTIAL WITH PELTIER THERMOCOUPLE PSYCHROMETERS

Ray W. Brown

Forestry Sciences Laboratory, Logan, Utah

The components of leaf water potential are often the most difficult parameters to measure in studies of plant water relations. Although osmotic potential is the one component most frequently measured, the values obtained with thermocouple psychrometers are often questioned. Recent reports suggest that psychrometric measurements of osmotic potential, using intact tissue that has been frozen and thawed, actually yield values of a complex sum of osmotic potential and part or all of matric potential. Evidence also suggests that this technique results in unusually large negative turgor pressures at low water potentials.

Data are presented comparing various methods of measuring leaf osmotic potential with Peltier thermocouple psychrometers. Osmotic potentials of tissue frozen in either dry ice or liquid nitrogen yield similar results, but suggest that the leaf material should not be exposed to the open atmosphere before, during, or after freezing. Data are discussed comparing osmotic potential values of intact frozen and thawed leaves, expressed sap from the same leaves, and the macerated tissue, over a broad range of leaf water potentials. Evidence is presented which indicates that, at low water potentials at least, osmotic potential measurements of intact frozen and thawed tissue are indeed complicated by the matric potential component.

MATRIC POTENTIALS IN PLANT TISSUES: ESTIMATION FROM MEASUREMENTS WITH THERMOCOUPLE PSYCHROMETERS

Lee N. Miller

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Matric potential (ψ_m) is a measure of the lowering of chemical activity of water which results when water is bound at interfaces with solids. Such binding occurs in plant cell walls and in cytoplasm. Although significant matric potentials may develop in some dehydrating plant tissues, ψ_m has seldom been evaluated in studies in plant water relations. Ignoring this component may introduce errors in estimates of the contribution of solutes (ψ_s) to the total water potential (ψ_w). Some estimates of bound water and ψ_m have been based on measurements which evaluate the deviation of ψ_s from ideal solution behavior in dehydrating leaf tissue. In this method, thermocouple psychrometer measurements of live and dead (frozen and thawed) tissue are related to parallel measurements of relative water content. An alternative method involves the direct measurement of ψ_m in homogenized cell wall preparations. These methods do not allow an absolute measure of the average ψ_m because of the presence of an unknown quantity of ions in cell wall solutions. As a first approximation, they indicate that ψ_m may be important in the water relations of leaves with small, thick-walled cells, especially at low water contents.

USE OF ISOPIESTIC TECHNIQUE IN THERMOCOUPLE PSYCHROMETRY

J. S. Boyer

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III. Application to Plants

A null or isopiestic technique which employs matching vapor pressures is used to measure the water potential of leaf tissue. When the tissue is equilibrated so that gradients in leaf water potential are negligible, the method gives highly reproducible values. When small gradients are present, water potentials indicated by the psychrometer are close to equilibrium values. However, when large gradients are present, water potentials appear to differ from equilibrium values. Non-equilibrium values therefore appear more ambiguous than equilibrium values.

Leaf water potentials measured during recovery of leaves from water deficits can be predicted from a diffusion equation for a plane sheet and suggest that thermocouple psychrometers sense the potential of most of the cells in the tissue. The time required for tissue to equilibrate appears to be influenced by the ability of the tissue to conduct water.

A TEMPERATURE COMPENSATED LEAF PSYCHROMETER FOR *IN SITU* MEASUREMENTS OF WATER POTENTIAL

C. Calissendorff and W. H. Gardner

Washington State University, Pullman, Washington

Water potentials may be measured *in situ* on plant leaves through use of a thermocouple psychrometer built to minimize temperature dependence and to permit correction for unavoidable temperature differentials between

the leaf surface and the position of the psychrometer junctions in the psychrometer chamber. The psychrometer junctions have the same thermal mass and are located as nearly as possible in the same heat exchange environment so that temperature difference between the wet and dry bulb are due solely to evaporation. An additional pair of thermocouples senses the temperature difference between the psychrometer junctions and the leaf surface. This psychrometer has been used successfully on corn plants growing outside, and is useful wherever temperature variation makes conventional psychrometers inoperative.

SEEDLING EMERGENCE FROM SOIL AS INFLUENCED BY CHANGING SOIL WATER POTENTIALS AND BY SEED PRETREATMENT WITH SOLUTIONS OF KINETIN AND GIBBERELLIC ACID

W. T. McDonough

Forestry Sciences Laboratory, Logan, Utah

Emergence from soil of seedlings of four grasses (smooth brome, crested wheatgrass, intermediate wheatgrass and Russian wild rye) in relation to several changing soil water potential regimes was determined. Compared to optimum conditions during peak emergence (water potential range of -0.6 to -1.2 bars), emergence was successively halved with decreasing ranges of water potential (-0.8 to 3.0 bars and -.16 to 4.2 bars), and there was little difference in response among the species. Pretreatment of seeds in solutions of 10 ppm kinetin or 500 ppm GA_3 for 8 hours before planting had a small, but significant effect on emergence of crested and intermediate wheatgrass, compared to the emergence of water-pretreated seeds or seeds planted air-dry. The growth regulator effect may be explained more in terms of more rapid shoot elongation of the pretreated seeds rather than in increased imbibitional uptake or retention of water by these seeds.

GROWTH RATES OF NATIVE GRASSES AND SOIL WATER STRESS AS MEASURED WITH THERMOCOUPLE PSYCHROMETERS

L. E. Eddleman and T. J. Nimlos

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Agropyron spicatum, *Festuca scabrella*, *Calamagrostis canadensis* and *Carex geyeri* exhibited marked differences in their growth responses to soil water stress and atmospheric stress. Pot experiments were conducted in growth chambers under conditions of a high stress atmosphere (HSA), 90° - 70°F day-night temperature and 10% RH and under a low stress atmosphere (LSA), 70° - 50°F day-night temperature and 80% - 50% day-night RH. An inverse relationship was found between soil water stress and growth. Growth rates were lower under the HSA than the LSA, except that the growth rate of *Agropyron spicatum* at soil water stresses of less than -3.5 bars was greater under HSA.

Agropyron spicatum, *Festuca scabrella*, and *Calamagrostis canadensis* ceased growth in the HSA at -5.0, -9.5, and -12.5 bars of soil water stress respectively and in the LSA at -12.5, -12.5, and -27.0 bars of soil water stress respectively. Death of leaf tissue occurred at soil water stresses ranging from -25 bars for *Calamagrostis canadensis* (HSA) to -82 bars for *Agropyron spicatum* (LSA). Immature plants of *Calamagrostis canadensis* grown in a HSA ceased growth at -2 bars of soil water stress and tissue death occurred at -4 bars.

Carex geyeri proved to be very difficult to work with, however, in that HSA growth ceased at -5.5 bars of soil water stress and death occurred at -36 bars.

SESSION V. APPLICATIONS OF PSYCHROMETRY IN MICROMETEOROLOGY

Moderator: C. B. Tanner

University of Wisconsin

PSYCHROMETERS IN MICROMETEOROLOGY

C. B. Tanner

University of Wisconsin, Madison, Wisconsin

Psychrometers have the principal advantage of reasonably simple construction and fairly uniform behavior under adequate ventilation. They have the disadvantage of a nonlinear relation between the measured temperatures and either vapor pressure or relative humidity. The nonlinearity complicates sampling under changing ambient humidity.

The simpler features of the psychrometer theory and errors associated with the common psychrometric measurements have been described. The advantage of differential psychrometry for testing psychrometers for ventilation, radiation errors, and stem heat flow are indicated by the error equations.

ON THE CONSTRUCTION AND USE OF CERAMIC WICK THERMOCOUPLE PSYCHROMETERS

L. W. Gay

Oregon State University, Corvallis, Oregon

Psychrometers for micrometeorological research should be sensitive, durable, portable and simple to operate. In 1967, Fred J. Lourence of the University of California-Davis reported his development of a thermocouple psychrometer that possessed these characteristics to an unusual degree. The unique feature of Lourence's design was a ceramic wet-bulb element that showed promise of eliminating the wick feed problems that are commonly encountered in wet-bulb psychrometry.

This paper describes my construction and tests of the Lourance psychrometer, along with observations on performance during two field seasons. Some modifications were made in Lourence's original design in order to enhance the ease with which a number of psychrometers can be combined into a system for micrometeorological research. This system can handle up to 12 psychrometers. I also discuss and evaluate characteristics of the system's other components: a heated reference junction, the recorder, connectors, cables, and instrument supports.

In addition to the basic simplicity of construction, my experience confirms that the ceramic wet-bulb design of Lourence offers a number of advantages over conventional psychrometers. Its high accuracy, when used with care and appropriate recording equipment, can define the gradients of temperature and vapor concentration in the atmospheric boundary layer with a precision sufficient for a variety of micrometeorological analyses.

PSYCHROMETRIC MEASUREMENTS AS USED FOR STUDIES OF COLD AIR LAKES

Inge Dirmhirn

Utah State University, Logan, Utah

Electric psychrometers were used for profiles of temperature and humidity in a large sink in Middle Europe. This was part of a study to determine the causes and development of cold air lakes in middle elevations in the Alps. Temperature minima of sometimes less than -50°C (-32°C during the measurements) were recorded and a strong vertical vapor flow towards the snow surface could be encountered.

DESIGN AND CONSTRUCTION OF A THERMISTOR PSYCHROMETER SYSTEM FOR RECORDING OF ATMOSPHERIC RELATIVE HUMIDITY IN REMOTE AREAS

Bland Z. Richardson

Forestry Sciences Laboratory, Logan, Utah

This paper describes a low cost relative humidity recording instrument for making continuous recordings over two-week periods. The device is capable of better than ± 3% accuracy. The unit records on a strip chart recorder and is powered by a 12-volt electrical system. Charging systems and electrochemical devices, capable of deep cycling (extreme discharge and recharge), are also discussed.

APPENDIX III

SYMPOSIUM ON THERMOCOUPLE PSYCHROMETERS

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APPENDIX IV

PSYCHROMETRY IN WATER RELATIONS RESEARCH[1/]

Proceedings of the Symposium on Thermocouple Psychrometers

Edited by

Ray W. Brown

Bruce P. Van Haveren

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