

## A SYSTEM FOR AUTOMATICALLY MEASURING AND RECORDING SOIL WATER POTENTIAL AND RAINFALL

P.S. BLACKWELL\* and M.J. ELSWORTH\*\*

\**Soil Scientist for the Agricultural Development and Advisory Service, stationed at ARC Letcombe Laboratory, Letcombe Regis, Wantage, Oxon OX12 9JT (Great Britain)*

\*\**Long Ashton Research Station, Long Ashton, Bristol BS18 9AF (Great Britain)*

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### ABSTRACT

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A system is described for the automatic simultaneous measurement and recording of soil water potential and rainfall. Tensiometers with fluid scanning switches and pressure transducers measure soil water potential. The fluid switch system also measures water depth in a series of bottles collecting rain from a catching trough. A versatile electronic system controls the rate and frequency of scanning by the fluid switch; a data logger collects the tensiometer and rain gauge signals and calibration values for calculating hydraulic potential and depths of collected rain. The system has been tested for accuracy, reliability and response to rapid changes of water potential and rainfall.

### INTRODUCTION

Measurements of soil water potential are increasingly becoming a routine part of agricultural and geomorphological research. Interest ranges from intensive measurements of soil water movement in laboratory experiments to extensive examination of patterns of soil water potential at remote field sites (Anderson and Burt, 1977). Soil water tensiometers have often been used to measure potentials greater than  $-80$  kPa and have usually been connected to mercury manometers to measure their internal pressure (Webster, 1966). The substitution of manometers by electronic pressure transducers offers a much more versatile system of instrumentation with faster response to changes of soil water potential and continuous recording of data at remote sites and inconvenient times (Institute of Hydrology, 1975).

Instrumentation with pressure transducers is more economical if one transducer can be shared among a number of tensiometers; this is possible with a fluid scanning switch making sequential fluid connection between one instrument and a number of others. Watson (1965) used a manually operated

switch, but the commercial availability of automatic fluid switch systems, originally developed for aero-space research, has provided greater impetus to their application in more recent years.

Rice (1969), Lee-Williams (1978) and Burt (1978) have all successfully used fluid switch systems to monitor tensiometers with a single pressure transducer in field experiments. These authors overcame a number of technical problems, such as leakage of water, intrusion of air, influence of temperature on internal pressure and equilibrium time between valve changes; their results were displayed on a chart recorder. The electronic controls of the published fluid switch systems have limited versatility and the scanning systems were usually operated continuously, with long periods at each position (2.5–30 min minimum). Data logging systems, with associated computational facilities, now offer considerable advantages over chart recorders. The scanning system controlling the valve is best operated intermittently, with short periods of measurements of complete cycles of a fluid switch separated by long intervals when no measurements are taken. Soil water potential and rainfall are often recorded separately, but the use of fluid switch systems in combination with a data logger offers the opportunity to incorporate both kinds of measurement in one system.

We have described a fluid switch system developed for use in connection with a lysimeter experiment simulating waterlogging of field soils (Cannell et al., 1980) and with a field experiment examining drainage patterns of a clay soil (Letcombe Laboratory Annual Report, 1980). On the lysimeter installation, the system includes a device to automatically monitor rainfall.

## DESIGN

The lysimeter installation has been described previously (Cannell et al., 1980). It includes below-ground access so that tensiometers can be installed through the walls of the lysimeters, and this also allows fluid switches and pressure transducers to be located close to a data logger. The lysimeters contained sandy loam (Skipwith series) and clay (Evesham series) soils.

The tensiometers were constructed by mounting porous ceramic cups (Soil Moisture Equipment Corporation, model 2131, bubbling pressure of 100 kPa) in rigid plastic bodies; these could be installed vertically or horizontally. Connection was made from the inside of the cup to the fluid switch by a nylon tube (0.32 cm outer diameter, 0.1 cm inner diameter) while another tube and clamp allowed the instrument to be purged by one operator (Fig. 1). Connections between nylon tubes were made with captive rubber seal brass couplings or tight, greased, sleeve connections.

The rain gauge was a rectangular catching trough (12.5 × 80 cm) draining water into a series of three collecting bottles mounted 1 m below ground in an access tunnel of the lysimeter installation. Each bottle syphoned water into the next when filled. Each bottle in the series had a greater horizontal cross-section than the next (Fig. 1). This allowed measurements of rainfall from

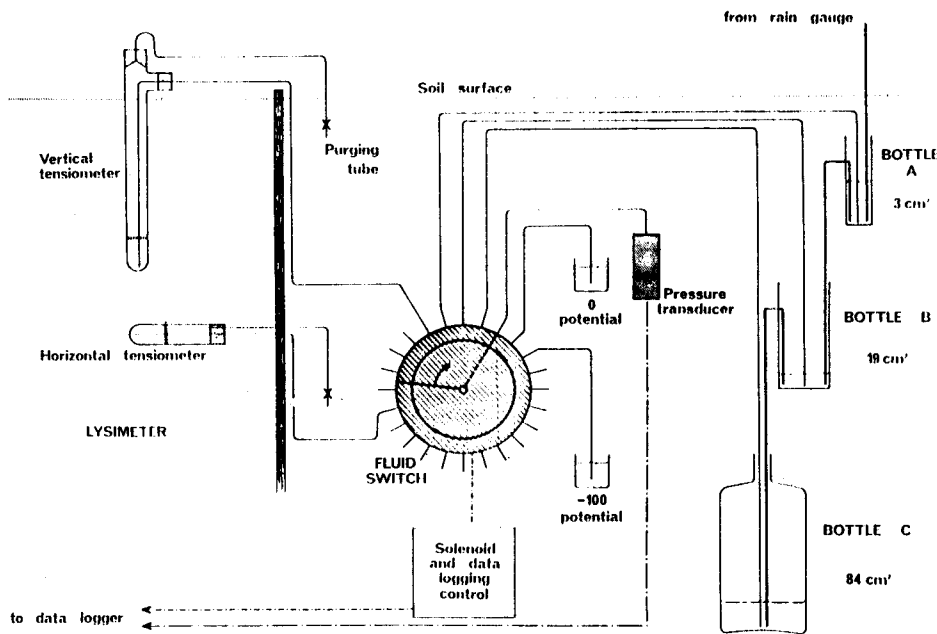


Fig. 1. Schematic diagram of the fluid switch system; the horizontal cross-sectional area of each rain collection bottle is indicated.

0.1 mm to 10 mm in increments of 0.1 mm according to the amplification of the depth of collected water by the bottles (333, 53 and 12 fold, respectively) and the frequency of measuring the water pressure on the bottoms of the bottles.

Each port of the 24 port fluid scanning switches (Scanivalve Corp. W 0602 1P/24T) was connected to a tensiometer, the bottom of a collecting bottle of the rain gauge or a container of water acting as a reference potential (Fig. 1). Reference potentials for each switch were provided by water surfaces at 0 and -100 cm of water suction relative to the pressure transducer diaphragm. These allowed routine calibration of the transducers and accounted for changes in atmospheric pressure. Valve switching was made by a solenoid driven stepping motor (Scanivalve Corp. WS5 24).

The common port from each fluid switch was connected to a strain-gauge diaphragm pressure transducer with a range of 0-200 kPa (Bell and Howell Ltd. BHL.4100.00.01M0, 0-2 bar Absolute). Each transducer was orientated with its diaphragm in a horizontal plane and could easily be replaced by a syringe when the system was purged.

Millivolt signals generated by each pressure transducer were recorded on separate channels of a data logger (Stogate data systems).

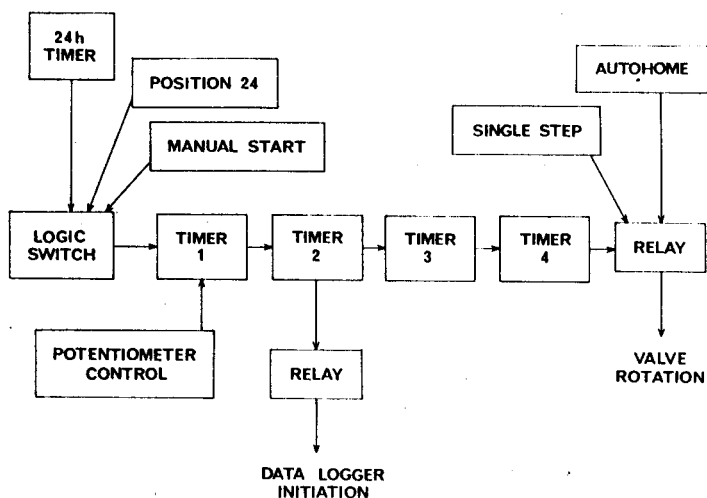


Fig. 2. A simplification of the electronic circuits controlling the solenoid drive and initiation of the data logger. Arrows indicate the direction of electronic impulses. The logic switch is opened by the 24 h timer or the manual start and closed by the valve being in position 24 (last position). The delay of timer 1 is variable. Completion of delay on timer 2 operates a relay to initiate the data logger and generates a series of impulses through timers 3 and 4 and operates another relay to rotate the valve. The valve relay can be overridden by the single step or autohome control.

The solenoid drive and initiation of data logging were controlled electronically by a system (Fig. 2) housed in the same enclosure as the fluid switches and pressure transducers. Full details are available from the authors. The system was originally powered by mains electricity (240 V AC), but could be adapted to use a portable power supply. Fully automatic operation was controlled by a 24 h timer. This began a complete scanning sequence by the fluid switch, i.e. 24 steps, by opening an electronic logic switch. The end of the complete sequence was identified by the valve being in position 24 (the last position of the cycle) which closed the logic switch and stopped the operation. During semi-automatic operation the sequence was initiated by a manually operated switch, and the stop after one complete cycle could be overridden if necessary by keeping this switch closed. The delay time between stepping from one port to another could be varied from 30 s to 5 min by an integrated timing circuit controlled by a potentiometer. Timing circuits also co-ordinated the initiation of the data logger and the activation of the solenoid drive. Further controls allowed step by step operation of the fluid switch, or a return to the first position. A series of illuminating diodes revealed the state of operation of the system. Scanning sequences were made routinely at 24, 12 and 4 hourly intervals or continuously (i.e. approximately 1 h for a 2 min valve delay time) if very rapid changes were being monitored.

## DATA PROCESSING

After initiation, the data logger electrically scanned the output from the pressure transducers for each position of the fluid switch. A record of each fluid scanning sequence with the time of each electrical scan was made through the data logger onto printed paper and punched tape at a remote console. The tape was processed by computer to calculate the water potential at each tensiometer and pressure of water at the bottom of the rain collection bottles during each fluid scanning sequence. The reference potentials recorded during each cycle of the fluid switches were used for calibration of the pressure transducer signal.

## TESTING

The accuracy, response and reliability of the system were assessed. Accuracy was estimated from independent calibration of the pressure transducers and examination of their analogue signals during a scanning sequence. The performance of the transducers was within the manufacturer's specification (maximum error  $\pm 0.1\%$  full scale). Pen recorder traces of the transducer output showed that a maximum of 2 min was required for equilibrium to be obtained after the most extreme difference of potential between two successive measurements on the sandy soil (i.e. 80 kPa). Longer periods for soil of lower conductivity are quoted by Rice (1969).

Temperature fluctuations also influenced the signal from tensiometers with nylon tubing exposed above-ground. Variations of approximately  $\pm 1$  cm of water pressure could be identified, this is more than expected by Lee-Williams (1978) but less than observed by Rice (1969).

The response of the system to rapid changes of water potential was estimated from measurements made during the drainage of lysimeters. Water-tables were dropped from the surface to 90 cm depth by lowering an outflow weir (Cannell et al., 1980). Fig. 3 shows the record of changes of hydraulic potential (referenced to 0 at the soil surface) made from continuous operation of the fluid switch system; certain of the data are omitted for clarity. The movement of the free water surface from the soil surface to 85 cm depth in 14 h was easily measured by the system. The very rapid reduction of potential at 110 cm depth was attributed to the close proximity of the drainage outlet. The accuracy of individual readings was assessed by the deviation of measured water potential from 0 when the free water surface and soil surface were coincident. The range of deviations ( $\pm 1$  cm of water pressure) was less than those expected by Burt (1978) for measurements at field sites. In longer-term tests during 3 months of early summer the tensiometers failed at water potentials below 80 kPa; otherwise no major problems occurred over a 9 month operating period.

Rainfall collected by the rain gauge and recorded by changes of pressure in the collection bottles by the pressure transducer corresponded to independent



measurements of rainfall at the same site. The change in negative pressure between two successive scanning sequences revealed the change of water depth in each bottle, and the rainfalls equivalent to the depth changes in each of the bottles (A, B and C) were added to give the total rainfall between successive scanning sequences. Unlike the daily observations using standard rain gauge, the fluid switch system allowed the distribution of rainfall over a 24 h period to be followed closely and related to changes of water potential. For example (Fig. 4), a rapid rise in soil water potential soon after the onset of rain was clearly illustrated by scanning sequences at time intervals of approximately 45 min.

## CONCLUSIONS

Collection of soil water potential and rainfall measurements can be made conveniently and automatically at a variety of frequencies (24 h — 45 min according to soil conductivity) if a fluid switch system, as described above, is used. The benefits over existing published methods include simultaneous monitoring of rainfall, recording the results on a data logger, and more versatile control of the sequence of operations and frequency of scanning. The system has been tested for accuracy, reliability and response to rapid changes in water potential and rainfall and seems suitable for use in agricultural and geomorphological research.

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