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Technology

A Sensor for Monitoring Water Uptake by a Simulated Plant Root

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An optoelectronic device for measuring very slow rates of flow through a simulated plant root was designed, constructed and tested in the laboratory of Agricultural Engineering Department, University of Newcastle upon Tyne, England, during the period from 1985 through 1987. 'Transducers' were used to monitor the advance rate of meniscus through a capillary glass tube. The transducers consisted of a small piece of plastic (Tufnol), a 6 mm filament bulb and a phototransistor unit. The time recorded by each transducer was printed out in a microprinter. The optoelectronic device reported in this paper can be used in the monitoring of soil water extraction by a physically simulated plant root which would ultimately allow plant water stress to be used directly in the control of irrigation.

Key word: Optoelectronic device, Plant root, Transducer, Meniscus, Irrigation.

Introduction

The success of irrigated agriculture depends mainly on timely and accurate application of irrigation water (Ponambalum and Adams 1985; Hook *et al* 1984; Geiser *et al* 1982) which is known as irrigation scheduling. Existing irrigation scheduling strategies are mainly based on soil and climatic conditions (Rhoades *et al* 1981; Clawson and Blad 1982; Doorenbos and Pruitt 1977) but the soil moisture extraction by the plant root is a function of soil, weather parameters and the plant itself. Hence a simulated plant root would be a reliable and dependable tool for irrigation sceduling purpose.

The rate at which soil-water enters into a single root is very low (Sanders 1971; Tinker 1976). Flow measuring devices available at present are not suitable to measure such a slow rate of flow (Adeoye and Rawlins 1991; Canny and Phillips 1963). An example of a slow flow measurement problem is in irrigation scheduling where the uptake pattern of water by the plant root must be monitored. One method of monitoring the water uptake by the real plant is to develop a physical root model that could be tested under laboratory conditions (Ahmed 1987). During the process of developing this model it became necessary to measure very low rates of flow into the simulated root. The rate of observation was only possible by allowing it to flow through a capillary glass tube of 1 mm inside diameter. Therefore, for accurate and precise monitoring of soil moisture extraction by the simulated plant root, it was necessary to develop a system to sense a slowly moving meniscus inside a capillary glass tube.

Experimental

Moving fluid in a capillary glass tube may be detected at discrete points using a light source and a phototransistor. The flow rate can be calculated by observing the times at which the fluid passes particular points. Given the long time intervals to be measured, the design of the optoelectronic device was based on a real time clock interfaced to a microcontroller unit. The hardware consisted of three sections:

(a) Optoelectronic units
(b) Interface unit
(c) Timing and Control unit.

(a) Optoelectronic units. A 6 mm filament bulb (GI 136 Philips) powered by 12v was used in conjunction with a phototransistor (TIL 81) to detect the meniscus. Each bulb/ phototransistor combination (transducer) was mounted in a Tufnol holder encircling the capillary tube as shown in Fig 1. The working fluid contained a black dye to make the fluid opaque to visible light. Given a bulb minimum operating current of approximately 20 mA, and a set of 24 transducers, power consumption is an important design consideration especially for field application. The minimization of field wiring should also be considered. Both requirements were accommodated by having only one bulb energized at any instant of time. Each set of 24 transducers had its own local interface board.

(b) Interface unit. The interface unit controls the switching of bulbs and interrogates the phototransistors. It was con-

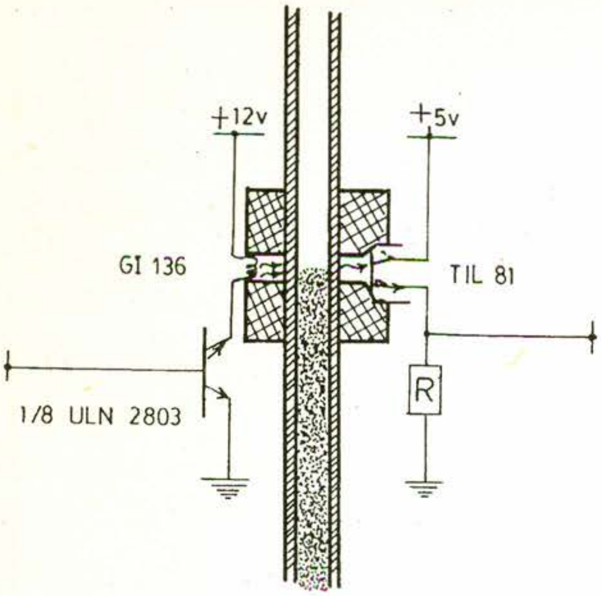

Fig. 1. Bulb/phototransistor combination mounted in a Tufnol holder.

nected to the timing and control unit via a seven-conductor cable. Three address lines and three chip select lines were used with three three-to-eight decoders (74HC237) to select one bulb out of twenty four via a high current Darlington driver (ULN2803). The same address and chip select lines were used with three analogue multiplexers (CD4051) to select the appropriate phototransistor to drive a single line to the timing and control unit via Schmidt triggers. The use of CMOS technology wherever possible limits the power consumption of the interface unit. The interface unit may be controlled by the timing and control unit described below.

(c) Timing and control unit. This unit consisted of hardware and software i) Hardware. The timing unit was based on a real time clock (HD146818P) controlled by an eight-bit microcontroller (UPD80C39). The clock had a battery backup. The processor could address only four kilo-bytes of programme memory. The interface unit was controlled via one port of a parallel input-output (PIO) device (UPD81C55); a second port on this device was used to drive a parallel printer. External communication with the system was via a 4x4 keyboard in conjuction with a two line by forty character LCD dot matrix display. The phototransistor output from the interface board was connected to the in put line (TO) on the processor and can be interrogated directly under software control. When operated without the printer the hardware consumed approximately 50 mA. *(ii) Software:* The software was written in assembler and contained the following major code segments:

Control of interface unit. The next element to be triggered was selected by writing the appropriate address and chip select byte to port A of the PIO device. The input line TO was polled and when triggered the time was read and recorded. The next element was then selected and the process repeated until all the elements were triggered.

Utility routines. These were used to set up the clock and to initialize the system for the number of the first element to be triggered and the total number of elements in use. When the system is battery powered, the recorded data may be retrieved using the keyboard and display; when it is mains powered, the recorded data may be logged into integral printer.

Results and Discussion

A. Calibration. In the prototype system seventeen transducers were placed along the length of a 'snake-like' capillary glass tube (1 mm internal diameter and 4 mm external diameter) maintaining a distance of 90 mm between the transducers. Due to the internal surface roughness of the glass tube and the inevitable slight displacement of the transducers during their final setting, the internal volume of the glass tube between consecutive transducers was not identical. The actual volume between consecutive transducers was determined using a graduated precision burette. Six different known flow rates were allowed to pass through the glass tube. The correspoding flow rates as detected by the optoelectronic device were calculated on the basis of recorded meniscus travel time and volume between two consecutive transducers. A relationship was found between applied and measured flow rates for three sections of the capillary glass tube. A tight cluster of points around a forty five degree line indicated a very close agreement between the applied and measured flow rates. A similar pattern was obtained for all the remaining sections of the glass tube. Therefore, it is evident that the optoelectronic device can accurately monitor the soil moisture uptake by a simulated plant root. Hence the device can safely be used for irrigation scheduling purposes.

A sensor for monitoring soil moisture uptake as described herein or of similar nature has not been developed so far. Fischbach *et al* (1970) designed controls for an automatic surface irrigation system using tensiometers to sense the matric potential and initiate irrigation. Austin and Rawlins (1977) described an opteoelectronic level detector for mercury manometers and they reported that the detectors and a controller using TTL (transistor transistor logic) circuits were used to successfully control irrigation on field plots.

B. Application. The prototype sensor was used to monitor the rate of soil water extraction by a simulated plant root under laboratory conditions. Various textured soils each having different soil water potential were used for the experiment. The sensor was found to fucntion properly and results were consistent with the soil texture and corresponding soil water content. The water uptake patterns for sandy loam and clay loam soils are represented in Fig 2. It is evident from the figure that the rate of water uptake decreased with the advance of time. Similar results were also reported by Reicosky *et al* (1972).

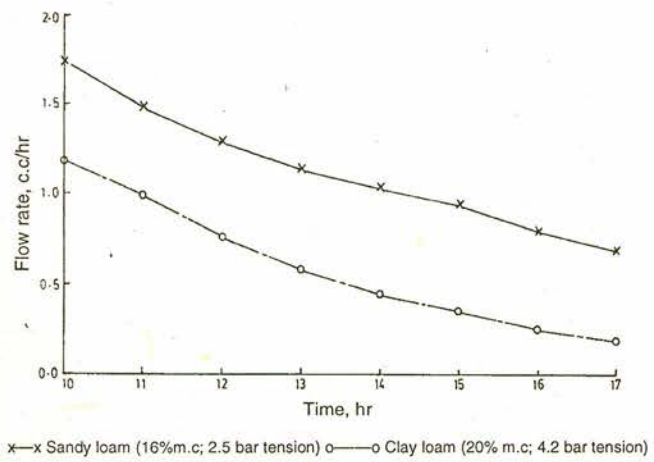

Fig. 2. Soil water uptake by a root model as measured with transducers.

The water content of a soil increases with the appliction of irrigation. The effect of irrigation on the water uptake behaviour of the root model and performance of the sensor was studied and illustrated in Fig 3. It was observed that the uptake rarely increased rapidly immediately after the application of simulated irrigation water and then declined abruptly.

Figs 2 and 3 illustrate that the prototype sensing device can successfully be used to monitor flow rate patterns under various conditions. Based on soil characteristics, type of crop and growth stage, and meteorological demand, a predetermined time can be selected (on the basis of optimum management allowable depletion level) for the meniscus to travel between transducers when a particular root model is used. If the time taken for the meniscus to travel between any two consecutive transducers is greater than the preselected time, then irrigation should be applied. Use of such transducers allows simulated plant water stress to be used directly for the purpose of irrigation scheduling.

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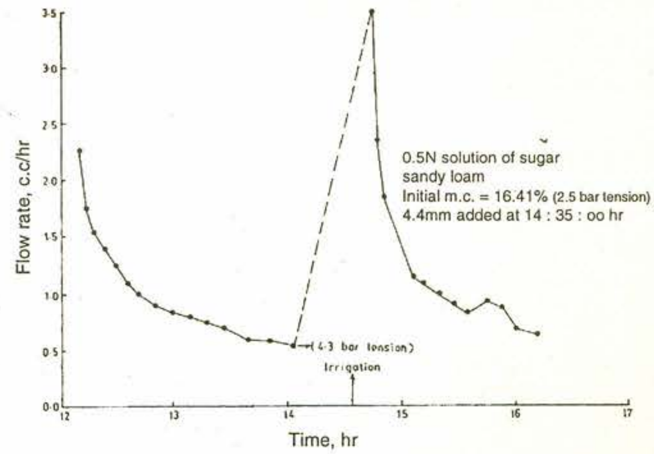

Fig. 3. Effect of irrigation on water uptake rate using sandy loam.

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