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A COMPUTERIZED ONE-STEP OUTFLOW METHOD FOR MEASUREMENT OF SOIL WATER DIFFUSIVITY

by

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ABSTRACT

Collection of unsaturated hydraulic conductivity (K) data is extremely time-consuming and costly due to the complex nature of the measurements. One of the simplest methods is the one-step outflow technique which measures soil water diffusivity (related to K). Although this technique is currently being used, there is a need for a reduction in the labour required for the precise collection of the outflow data over time. A study was conducted to develop an automated system for measuring and recording water outflow collected during the one-step technique.

For the one-step method, saturated soil cores in contact with a ceramic plate are subjected to a pressure and the resultant outflow of water is collected and measured at selected time intervals until outflow ceases. During this study, outflow was converted to a proportional electrical signal by directing the outflow into a 2 m long glass tube (7 mm diam.) connected to a pressure transducer which precisely monitored the hydraulic head created by the outflow volume. The signal monitored by the pressure transducer was transmitted to a computer through a datalogger. A BASIC program for the computer was created to collect and record the signals at selected time intervals. For this experiment, the intervals were 1 minutes apart at the beginning and were gradually increased to 12 hours after one week. The sensitivity and accuracy of the system was tested by observing the response of the transducers at hydraulic heads of 0.00, 0.32, 0.64, 0.96, 1.28, and 1.60 m for 20 replications. The analysis of the data showed that the standard deviation was 5 mm (corresponding to 0.19 cm3) which suggests that this technique is sufficiently sensitive for measurement of the outflow. Since several soil cores can be automatically evaluated at one time (16 for this setup), the computerized one-step method may prove to be one of the more efficient and economical laboratory methods for measuring soil water diffusivity.

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INTRODUCTION

Upward water movement from a shallow water table or a subsoil with high water contents can contribute significantly to the total crop water requirement. Soluble salts also move with the upward flux of the water and are accumulated in the top layers often causing toxic conditions for plant growth. A precise prediction of upward water and salt movement is necessary for sustained crop production in semi-arid and arid regions with shallow water tables. It is also vital to know the intake rate of water after irrigation or rainfall, especially in the areas having high slope. This information is useful for dependable estimation of a site's potential for water storage and leaching of salts. The governing component for prediction of unsaturated water movement is the unsaturated hydraulic conductivity function of different layers of the soil profile. During the past few decades, many researchers have come forth with various techniques or have suggested modifications for in situ as well as laboratory measurement of soil water diffusivity (related to unsaturated hydraulic conductivity, K) of soils. (Bouma, 1973; Bouma, et al., 1974; Baker, 1978; Laliberte and Corey, 1967; Gardner and Midlich, 1962; Ahuja and El-Swaify, 1976; Ehlers, 1977; Gardner, 1974; Gupta et al., 1974; Passioura, 1976; Jaynes and Tyler, 1980.)

Collection of unsaturated hydraulic conductivity data is extremely time-consuming and costly due to the complex nature of the measurements. The one-step outflow technique is one of the simpler laboratory methods currently being used for measuring the soil water diffusivity, a property related to unsaturated hydraulic conductivity. Although Passioura (1976) simplified the analysis of one-step outflow data, it is not yet considered to be an economical technique, due to the extensive labor required in the precise collection of the data over time. A study was conducted to develop an automatic system for measuring and recording the necessary outflow data for the one-step technique to significantly reduce the manpower involved in such investigations.

MATERIALS AND METHODS

EQUIPMENT ASSEMBLY

In this study, water outflow was converted to a proportional electrical signal by directing the outflow into a long glass tube connected to a pressure transducer which precisely monitored the hydraulic head created by the outflow volume. The signal was transmitted to a

computer through a datalogger and recorded.

A schematic diagram of one channel of the computerized one-step outflow assembly is illustrated in Fig. 1. The actual system had the capacity for running 16 soil cores at one time and recording their outflow automatically at desired time intervals. In this setup, the soil cores were 66 mm in diameter housed in plexiglass containers which were fit in a pressure cell arrangement. High flow 50 kPa ceramic plates were used to minimize the effect of plate impedance on outflow rate. Both ends of the plexiglass soil core assembly were fitted with quick connectors for easy connecting and disconnecting.

A known weight of dry soil was compacted in the plexiglass cylinder with ceramic plates at the bottom to obtain approximately the natural dry bulk density of the soil. After sealing both ends with plexiglass pressure cell ends fitted with quick connectors, the cores and the ceramic plates were saturated in a vacuum. Suction was applied at the top inlet and of the soil core and air free water was allowed to enter very slowly from the bottom. The cores were then fitted in the outflow assembly as shown in Fig. 1. The main air pressure supply was controlled at the desired level through a sensitive air pressure regulator. For this study the pressure was kept at 19.3 kPa.

A Micro Switch 240PC 5.0 V pressure transducer was used as the sensing element to generate signals proportional to the volume of water flowing out of the core. To generate a signal, each transducer was fitted with a 2 m long glass tube and the water flowing out of the sample was directed into the tube using a 5 cm long No. 18 syringe needle. The needle was connected to the outlet of the sample core through .64 cm diameter teflon tubing connected to a quick connector. The hydraulic head created in the glass tube was proportional to the volume of water in it and the transducer would produce an electrical signal proportional to the hydraulic head. The diameter of the glass tube was selected dependent upon the core size and the expected volume of outflow so that the water head in the tube would not exceed 1.60 m. In the present setup four lengths of cores, i.e. 2, 4, 8, and 16 cm, have been selected with four replications. The corresponding diameter of each size of glass tube is 3, 4, 6, and 8 mm.

Entrapment of air occured in the water column for the two smaller tube sizes, especially in the initial period when the outflow rate was highest. The problem was solved by installing a cotton thread along the inner wall of the glass tube. The thread always remained saturated with water, thus providing a very high conducting path for quick flow of water through the tube without allowing air entrapment. Also evaluated was the response to injecting an air

bubble into the water in the glass tube. The air bubble did not remain in the water but moved out of the tube as the water flowed down along the thread pushing the air upward.

To avoid loss of water from the glass tube due to evaporation but to allow air to escape, the upper end of the glass tube was fitted with another syringe needle using tygon tubing The needle connected to the water outflow assembly passed through the wall of the tygon tubing into the glass tube as shown in Fig. 1. A double shut off valve was incorporated in the line between the glass tube and the transducer for easy insertion or removal of water from the glass tube through the bottom whenever necessary. This provision was especially helpful for calibration and testing purposes.

A 12 V heavy duty marine battery in conjuction with a voltage stabilizer was used as a power source for the operation of the transducers. Voltage stability is very important as any variation in it would shift the calibration accordingly.

A 16 channel digital output datalogger was assembled by the Electronics Instrument Shop of the Department of Physics at the University of Missouri-Columbia for collecting the information. The active range of the datalogger for reading an incoming signal is 0 to 1 V. A signal greater than 1 V will appear only as 1 V. Therefore an alignment is necessary between the transducer signal and the range of the datalogger to cover the entire working range of the transducer response. For this purpose a special provision has been provided in the datalogger to amplify or reduce the input signal to fit in the correct range. In this experiment, the alignment for each channel was done by creating a 1.6 m water head in the glass tubes and tuning each channel to fit the signal generated by the transducer in a 1 V range.

The signal from the datalogger was transmitted to an Apple II microcomputer which stored the data on a floppy disk according to selected time intervals. The 12 V battery was also linked to the computer to prevent any interruptions due to electrical power failure.

Computer Software Development

Two separate computer programs written in BASIC were developed to operate the assembly. One program was for calibrating and testing the reliability of the setup. The second program was for recording the outflow data over time. This programs can easily be adjusted for investigating any number of cores between 1 and 16. The programs also have flexibility for

incorporating any function which indicates the frequency of measurements during the outflow experiment. Printouts of the programs are included at the end of the paper.

Equipment Performance Studies.

The performance of the transducers was evaluated by observing their response twenty times at hydraulic heads of 0.00, 0.32, 0.64, 0.96, 1.28, and 1.60 m. This was done by inserting water into the glass tubes through the double shut off valve at the base of the tube until the desired hydraulic head was achieved. Two different measurements of the voltage were recorded for each of ten replicates to provide a total of twenty determinations of the response of each transducer.

RESULTS AND DISCUSSION

Equipment Performance

The response of one of the transducers for twenty observations at hydraulic heads of 0.00, 0.32, 0.64, 0.96, 1.28 and 1.60 m is illustrated in Fig. 2. The width of the band at each hydraulic head represents the range in observed values. It is evident from the results that the response of the transducer during different runs was nearly identical. The statistical analysis of the data showed that the standard deviation was only 5 mm (corresponding to 0.19 cm3) which suggests that this technique is sufficiently sensitive for the measurements of outflow data for the one-step method.

Fig. 3 shows cumulative outflow from a soil core versus the square root of time. It is evident from the curve that the rate of outflow was the highest in the beginning and gradually decreased with the passage of time. From this curve, soil water diffusivity can be calculated as suggested by Passioura (1976).

Cost Benefit Analysis

One of the major benefits of this technique is the savings in manual labour. It should be pointed out that for the one-step technique more than 50 observations are needed to fully characterize the outflow behaviour for a soil core. Since the initial time interval between measurements must be kept very short, i.e. about 1 minute, one person is needed for each core at the beginning using the conventional method. At later stages, one person may be able to handle more than one soil core. On an average basis, it is estimated that for four soil cores, about four man

hours are needed for each day to collect the data. If the samples are run for 20 days, then 80 man hours are required to complete four samples, i.e. 20 man hours for each sample. However, for the computerized technique, a negligible amount of manual labor is needed, even for 16 cores. Another benefit of this system is the increase in the precision of the measurements during the initial period of outflow since the measurements are automated. This compares with the conventional method in which experimental error may be introduced due to the short time intervals at which outflow measurements must be taken. The efficiency of the computerized system can be further enhanced by increasing the number of cores without additional involvement of manual labor.

The estimated cost of materials for setting up a 16 channel system was about $10,000. If about 200 cores are investigated annually, this cost can be recovered in less than one year. If a bigger system is made for running a larger number of cores, then the economical benefits will be greater accordingly. Another important benefit is that in the computerized technique, data are directly transferred onto a computer disk, whereas in the conventional method, some time and labor is involved in the transfer of the data onto a computer disk.

Summary

In this study, a computerized one-step outflow technique which automates the collection of water outflow data to be used in determining soil water diffusivity is illustrated. The sensitivity of the transducers utilzed for measuring the outflow of water from soil cores appeared to be sufficient for accurately determining the amount of outflow over time. The major benefit of the system is the reduction in the amount of manual labor which is required in the conventional method. Another benefit is the improvement in the precision of the measurements during the initial period of outflow. Since several soil cores can be evaluated at a time, the computerized one-step outflow assembly may prove to be one of the more efficient and economical laboratory methods for measuring soil water diffusivity.

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REFERENCES

1. Ahuja, L.R., and S.A. El-Swaify. 1976. Determinig both water characteristics and hydraulic conductivity of a soil core at high water contents from a transient flow experiment. Soi Sci. 121:198-204.

2. Baker, F.G. 1978. Variability of hydraulic conductivity within and between nine Wisconsin soil series. Water Resources Res. 14:103-108.

3. Bouma, J. 1973. Use of physical methods to expand soil survey interpretations of soil drainage conditions. Soil Sci. Soc. Am. Proc. 37:413-421.

4. Bouma, J., F.G. Baker, and P.L.M. Veneman. 1974.
Measurement of water movement in soil pendons above the water table. Inform. Circ. 27, Geol. Nat. Hist. Surv., Univ. Ext., Madison, Wis.

5. Ehlers, W. 1977. Measurement and calculation of hydraulic conductivity in horizons of tilled and untilled loess-derived soil, Germany. Geoderma 19:293-306.

6. Gardner, W.R. 1974. The permeability problem. Soil Sci. 117:243-249.

7. Gardner, W.R. and F.J. Miklich. 1962. Unsaturated conductivity and diffusivity measurements by a constant flux method. Soil Sc. 93:271-274.

8. Gupta, S.C., D.A. Farrell, and W.E. Larson. 1974.
Determining effective soil water diffusivities from one-step out flow experiments. Soil Sci. Soc. Am. Proc. 38:710-761.

9.Jaynes, D.B., and E.J. Tyler. 1980. Comparison of one-step outflow laboratory method to an in situ method for measuring hydraulic conductivity. Soil Sci. Soc. Am. J. 44:903-907.

10. Laliberte, G.E., and A.T. Corey. 1967. Hydraulic properties of disturbed and undisturbed samples. p. 56-71. In Permeability and capillarity of soils. ASTM STP 417, Am. Soc. Testing Materials.

11. Passioura, J.B. 1976. Determining soil water diffusivities from one-step outflow experiments. Aust. J. Soil Res. 15:1-8.

BASIC program for recording outflow data in computerized one-step method.

```
100 REM TIME CARD IN SLOT 4 AND INTERFACE IN SLOT 2
150 POKE - 15869,0
200 POKE - 15870,255
300 POKE - 15861,129
350 X = - 15872:Y = - 15867:Z = - 15871
400 DS = CHRS (4)
450 DEF FN V (UL) = ((U * 256) + L) / 32767
500 DIM W(20),WS(20),BS (20),WO(20)
550 HOME
600 FOR I = 1 TO 6 : READ WS (I), BS (I):NEXT I
650 DATA FILE NAME ....., DATA 0
700 DATA DRIVE ....., 1
750 DATA NO. OF CHANNELES ..., 3
800 DATA INITIAL TIME INTERVAL .., 1
850 DATA B IN T = (DELTA T) + N B ..., 0.8
851 DATA LIMITING DELTA V ..... , 0.001
900 HOME: REM PRINT THE MENU
950 HOME
1000 FOR I = 1 TO 6
1050 VTAB 2 + 1 * 2:HTAB I
1100 PRINT I: " ": WS (I): : INVERSE : PRINT BS (I): NORMAL
1150 NEXT I
1200 VTAB 17: INVERSE
1250 PRINT " ENTER THE NUMBER YOU WANT TO CHANGE"
1300 VTAB 19:INVERSE
1350 PRINT "OR PRESS RETURN TO START LOGGING":
1400 NORMAL: INPUT XS
1450 J = VAL (XS)
1500 IF J IS = O THEN 1650
1550 IF J < O OR J > 6 THEN 900
1600 VTAB 2 + J * 2: HTAB 26: PRINT "     " : : INVERSE: HTAB 26: INPUT BS (J): NORMAL: GOTO 900
1650 FS = BS (1):D=VAL(BS (2)):CH = VAL (BS(3)) : TO = VAL (BS(4)) : B = VAL (BS(5))
1652 VO = VAL (BS(6))
1655 REM CLEAN THE FILE AND WRITE THE NUMBER OF CHANNELES ON IT.
1660 NO = O
1661 PRINT DS; "OPEN ";FS;",D";D
1662 PRINT DS; "DELETE"; FS
1663 PRINT DS; "OPEN "; FS
1664 PRINT DS; "WRITE ";FS
1665 PRINT CH
1666 PRINT DS; "CLOSE ";FS
1700 REM START LOGGING
1750 I = 64
1800 FOR C = O TO CH - 1
1850 POKE X,I
1900 POKE  Y,O
1950 U = PEEK (Z)
2000 POKE X,1
2050 L = PEEK (Z)
2100 W (C) = FN V (UL)
```

```
2150 I = I + 4
2200 NEXT C
2250 GOSUB 2300
2255 GOTO 2600
2300 REM TIME ROUTINE
2350 PRINT DS"IN 4"
2400 PRINT DS"PR 4"
2450 INPUT ":";AS
2500 PRINT DS"IN O"
2550 PRINT DS"PR#O"
2561 MO = VAL ( MIDS (AS,3,2))
2562 DA = VAL ( MIDS (AS,6,2))
2563 YR = VAL ( MIDS (AS, 9,21))
2564 HR = VAL ( MIDS (AS,12,2))
2565 MI = VAL ( MIDS (AS,15,2))
2566 SE = VAL ( MIDS (AS,18,2))
2570 RETURN
2600 REM WRITE TIME AND VOLTAGE ON DISK
2650 REM
2700 PRINT DS;"APPEND ";FS;",D";D
2750 PRINT DS;"WRITE ";FS
2800 REM
2850 PRINT MO
2900 PRINT DA
2950 PRINT YR
3000 PRINT HR
3050 PRINT MI
3100 PRINT SE
3150 FOR C = O TO CH - 1
3200 PRINT W (C)
3250 NEXT C
3300 PRINT DS;"CLOSE"
3350 NO = NO + 1
3355 REM CALLING DELTA T ROUTINE
3356 IF NO > 1 THEN 3370
3357 FOR I = O TO CH - 1:WO(I) = W(I) : NEXT I
3358 T = TO
3370 GOSUB 5000
3380 FOR I = O TO CH - 1:WO(I) = W(I): NEXT I
3385 T = DT
3400 REM WAIT FOR DT MIN.
3410 GOSUB 2300:CO = O:C1 = MI
3420 FOR J = 1 TO 500: NEXT J
1421 GOSUB 2300: REM GET TIME
3422 C2 = MI - C1 :REM NO OF MIN. AFTER THE LAST CHECK.
3423 IF C2 < O THEN C2 = C2 + 60: REM CORRECTION FOR HOUR CHANGE
3424 CO = CO + C2: REM TOTAL WAIT TIME
3425 C1 = MI:REM C1 THE LAST READING
3426 VTAB 17: INVERSE : PRINT "TIME ----";AS;"
3427 VTAB 19: PRINT "DELTA T= ";DT;"          ";"WAIT TIME = ";CO
3428 VTAB 21: PRINT "OBS=";NO:NORMAL
3435 IF CO > = DT THEN 1700
```

```
3440 GOTO 3421 : REM IF DT IS NOT REACHED THEN WAIT MORE
3450 PRINT : HOME
3500 INVERSE : PRINT "DO YOU WANT TO LIST THE FILE ?
Y/N ";
3550 NORMAL : HTAB 36: INPUT YS
3600 IF YS = "Y" OR YS = "YA" OR YS = "YES" THEN 3700
3650 GOTO 4550
3700 PRINT DS;"OPEN ";FS
3750 PRINT DS;"READ ";FS
3800 N = 0
3850 ONERR GOTO 4450
3900 INPUT "";C
4000 INPUT "";MO: INPUT "";DA: INPUT "";YR: INPUT ""; HR: INPUT ""; MI: INPUT "";SE
4050 PRINT MO;" ";DA;" ";YR;" "; HR;" ";MI;" ";SE;" ";
4100 FOR M = 1 TO C
4150 INPUT "";T
4200 PRINT T;" ";
4250 NEXT M
4300 PRINT
4320 N = N + 1
4350 GOTO 4000
4400 PRINT DS;"CLOSE"
4450 IF N < > 0 THEN 4550
4500 PRINT "THE FILE ";FS;" IS EMPTY "
4550 END
5000 REM DETERMINE DELTA T IN MIN.
5010 REM RETURN THE VALUE IN DT.
5020 REM IF DT = 0 THE LOGING STOPS.
5030 DT = DT + NO ^ B
5035 DT = INT (DT + 0.51): REM ROUND TO THE NEARST MIN.
5050 RETURN
```

BASIC program for calibrating transducers.

```
10 POKE - 15869,0
20 POKE - 15870,255
30 POKE - 15861,129
40 POKE - 15866,8
50 X = - 15872:Y = - 15867:Z = - 15871
60 DEF FN V (UL) = ((U * 2561 + L) / 32767
70 A = O:B = O:C = O:D =O:E = O:I = O
80 PRINT "TAKE LOAD OFF SENSOR ON CHANNEL O": PRINT "PRESS RETURN WHEN READY": PRINT
90 CALL - 676
100 POKE X,64
110 POKE Y,O
120 U = PEEK (Z)
130 POKE X,1
140 L = PEEK (Z)
150 A = A + U
160 B = B + L
170 I = I + I
180 IF I = 10 THEN GOTO 200
190 FOR T = 0 TO 10: NEXT T: GOTO 100
200 U = A / 10
210 L = B / 10
220 C = FN V(UL)
230 D = 1 - C
240 PRINT "BASELINE READ, PRESS RETURN TO READ LOAD"
250 CALL - 676
260 POKE X,64
270 POKE Y,O
280 U = PEEK (Z)
290 POKE X, 1
300 L = PEEK (Z)
310 E = FN V(UL) - C
320 F = (E / D) * 100
330 PRINT "SENSOR AT ";F;" OF FULL SCALE"; PRINT
340 PRINT "PRESS RETURN FOR NEXT READING"
350 CALL - 676
360 GOTO 280
```