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NOTE

SOIL WATER HYSTERESIS: TEMPERATURE AND PRESSURE EFFECTS

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ABSTRACT

The effects of transient temperatures and pressures on soil water hysteresis were studied under controlled laboratory conditions. Variations in ambient pressure and temperature caused small changes in soil water hysteresis. These changes suggest that at least two mechanisms may be present, neither of which is easily rationalized by the classical hourglass-shaped pore liquid jump model.

The variation between duplicate samples of a silty clay, a silt loam, and a loamy sand suggested that normal temperature and pressure changes in the field will not cause changes in soil water hysteresis that are larger than those due to natural soil heterogeneity. Consequently, soil water hysteresis curves measured in the laboratory on representative samples may be used in computer models of field situations.

Scientists constructing comprehensive computer models of soil water flow are increasingly concerned about soil water hysteresis. A common model for the hysteretic mechanism is an hourglass-shaped pore, which may empty or fill with water in discrete jumps when triggered by pressure changes across the air-water interfaces of smaller interconnecting pores. However, not all experimental data can be explained by this concept. For example, the hourglass-shaped pore model suggests that the volume of entrapped air would be less during drainage and greater during wetting, but the reverse occurs more often at low water tensions (Cary 1967). The hourglass-pore concept also suggests that the hydraulic conductivity will not be a unique function of water content, because the resistance to liquid flow in unsaturated soil increases rapidly as the thickness of the water films decreases. For any given unsaturated soil water content, the resistance to liquid flow should be least when all the films have a maximum thickness as compared to a nonuniform distribution where some interconnecting films remain thin at the expense of filling large hourglass pores. However, as shown by Vachand and Thong (1971), and others, hydraulic conductivity is very nearly a single-valued function of water content, but matric potential is not.

In spite of these conceptual problems, functions are being developed that describe soil water hysteresis reasonably well and are amenable to modeling with digital computers (Mualem 1973). These functions are based on laboratory observations of soil water hysteresis under constant temperature conditions. When the flow models are applied to practical problems, one must know whether fluctuations of temperature and air pressure in the field significantly affect soil water hysteresis. The work reported here concerns this question.

METHODS

Six cylinders, each containing 300 cm² of soil (Fig. 1), were filled with duplicate air-dried samples of three soils—a silty clay, B horizon (bulk density 1.35 g/cm³), a loamy sand arid surface soil (bulk density 1.4), and a silt loam arid surface soil (bulk density 1.3). The cylinders were submerged in a water bath so that the temperature could be held constant or varied as desired. The soils' liquid and gas phase pressures were controlled independently to develop the desired water tensions.

All treatments were subjected to water pressure cycles of 5 to 550 to 5 cm water tension with five steps for desorption and five for adsorption.

As shown in Table 1, hysteresis was measured at constant temperatures of 5°, 15°, and 25°C. Measurements were also made as the temperature cycled through continuous 24-hr periods of 25° to 15° to 25°C, and, in a more extreme test, as the temperature was continuously cycled from 25° to 5° to 25°C during an 8-hr period in which the 20°C temperature change occurred over 3-hr intervals. All the water contents were measured by observing the level in the burets when the soil temperature was 25°C. Soil gas phase treatments included one test at 200 cm of water below ambient, and a second where the gas phase varied from 800 to 250 to 800 cm of water below ambient as the liquid pressure remained constant at 805 cm of H_2O below ambient. Three to five days were allowed for equilibrium between each increment of pressure change. The complete experiment extended over 21 months.

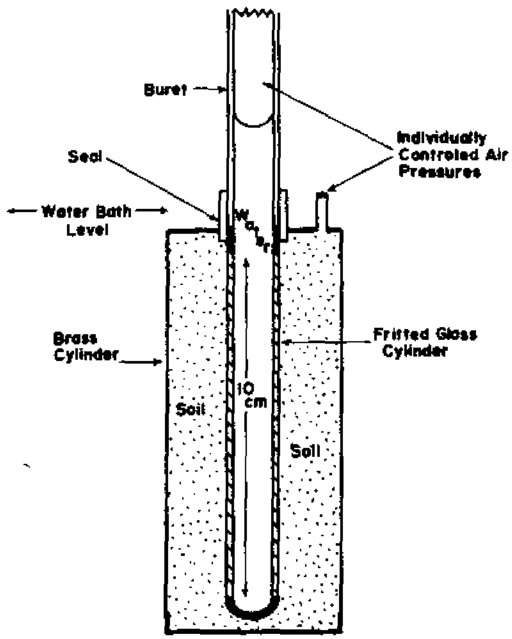

FIG. 1. Cross section diagram of the experimental apparatus.

RESULTS

Typical hysteresis curves for the three soils are shown in Fig. 2. All the data were plotted similarly, and the areas enclosed by individual loops were used as a criterion for whether hysteresis had been influenced by the treatments (Table 1). Significant differences were calculated individually for each soil texture from analysis of variance of the duplicate samples making up the seven treatments.

Some of the means for the silty clay were different at the 5 percent level. Based on treatment 7 as the laboratory standard, the cycling temperatures did affect hysteresis in the silty clay. Peak temperature gradients during the 8-hr cycle exceeded 0.5°C/cm and caused a calculated net vapor flux of about 0.04 mm that reversed direction every 4 hr. This reversal,

TABLE 1

Average areas enclosed by soil water hysteresis loops as affected by changes in temperatures and ambient air temperature. Units of the area are (1% water content change) × (10 cm H_2O tension). The treatments are listed in the order in which they were applied

	Treatments			Areas		
No.	Air pressure (cm H_2O below atmospheric)	Water pressure (cm H_2O below atmospheric)	Temperature °C	Loamy sand	Silt loam	Silty clay
1	0	5-550-5	25-15-25 24-hr period	108	100	50
2	0	5-550-5	5	105*	92	57
3	0	5-550-5	15	76	91	43
4	0	5-550-5	25-5-25 8-hr period	104	99	44
5	200	205-750-205	25	100	101	48*
6	800-250-800	805	25	126	124	37
7	0	5-550-5	25	100	86	34
		LSD, 95% confidence level		NS	NS	10

* Based on a single hysteresis loop; missing data point used in statistical analysis.

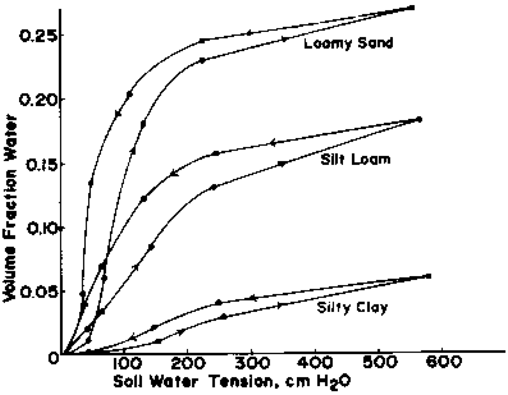

FIG. 2. Volume fraction of water withdrawn from three soils as a function of soil water tension under standard conditions of atmospheric pressure and 25°C.

coupled with any air-water interface instability caused by the cycling temperatures and evaporation-condensation sequences, did not drive the system far enough toward interior scanning curves to reduce hysteresis. Rather, the hysteresis increased and appeared to be influenced more by low temperatures than by cycling temperature per se (treatment 2, Table 1).

Some of the data in Table 1 may be time dependent. Even though the samples had gone through several adsorption-desorption cycles before treatment 1, they tended to hold more water each time they returned to the 5 cm of water tension starting point during the first 10 months of the experiment. This amounted to a 1 to 3 percent by volume increase in water content and may have been accompanied by a change toward decreasing hysteresis. For example, the areas of the loops shown in Fig. 2 were 5 to 8 percent greater than the areas created by treatment 7. Data shown in Fig. 2 were obtained between treatments 1 and 2, but under the same conditions as those for treatment 7.

Although statistical analysis for the silt loam and loamy sand did not show any significant difference at the 95 percent confidence level, this is not conclusive evidence that no real differences occurred. Treatments 6 and 7 tended to differ for both soils. Hysteresis appears to have been increased by reduced soil gas pressures. If significant amounts of entrapped air associated with the hourglass-pore model were involved, one might have predicted an opposite effect because the density of air being entrapped during desorption would be lower than that in the normal system under atmospheric pressure (Peck 1969; Cary 1967).

The three soils responded differently to the temperature and pressure variables. The 5°C constant temperature increased the hysteresis in the silty clay, but not in the silt loam or loamy sand. There was no difference between treatments 6 and 7 for the silty clay, but treatment 6 tended to increase hysteresis in the other soils. Although the trends for the loamy sand and silt loam may not be real, the data do suggest that soil water hysteresis may involve at least two different mechanisms: One is sensitive to temperature and is associated more with clay size particles; the other is sensitive to air pressure and is associated with larger soil particles and pores. Wilkinson and Klute (1962) noted that the temperature coefficient for soil water tension was about twice as great as one might calculate from the properties of pure water, and the coefficient increased as the soil particle size decreased. In the study reported here, holding the soil water tension constant at 95 cm while lowering the temperature from 35° to 5°C resulted in soil water inflows of 0.01 volume fraction for the silty clay, 0.0085 for the silt loam, and only 0.0065 for the loamy sand. These inflows also indicate the greater temperature sensitivity of the clay-water system. While mechanisms sensitive to air pressure may be involved with air-water interfaces and particle rearrangement, mechanisms sensitive to temperature are more likely associated with clay-water interactions, and/or involve the amorphous silica that coats most soil particles (Jones and Uehara 1973).

The data in Table 1 indicate that normal fluctuations of temperature and air pressure will not cause large changes in soil water hysteresis as compared to changes resulting from the soil heterogeneity inevitably encountered in the field. Exceptions may occur in the surface 2 to 3 cm when temperature variations are extreme, or for fine-textured soils with low temperatures. For most practical problems of computer simulation, normal temperature and air pressure changes will not significantly affect the requirements for programming hysteresis in the wet soil water range. Rose (1971) reached a similar conclusion for hysteresis in the drier soil ranges.

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