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Development of In-Situ Soil Water Measurement by Heat-Probe Method

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Abstract

Thermal conductivity of soil which increases linearly with the soil water content over a wide range of values of soil water content can be measured accurately by the twin transient-state cylindrical-probe method (twin heat probe method). An automated measuring system with a micro-processor was developed to measure the in-situ soil water content continuously in the field.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: soil water content, thermal conductivity, twin heat probe method

Introduction

It is important but difficult to measure the in-situ soil water content continuously in the field, because the measurement of the soil water content which consists of mass measurement, requires the use of the weighing or mass adsorption method. The former is a destructive method of measurement and the latter cannot be applied in the field due to the use of a gamma beam.

Therefore several methods were examined to determine the soil water content based on other physical properties, including soil water potential, neutron scattering, electrical resistance, etc. However, most of the methods currently used are not practical for routine application in the field.

The thermal conductivity of soil which increases linearly with the soil water content over a wide range of values of soil water content, can be measured accurately by the twin transient-state cylindrical-probe method (twin heat probe method). An automated measuring system with a micro-processor was developed to measure the soil water content in the field.

Principle and method

1) Principle

The twin transient-state cylindrical-probe method (twin heat probe method) was developed to measure the thermal conductivity of soil[1].

When an infinitely long line source of heat is embedded in an infinite, homogeneous, isotropic medium, the increase of the temperature of the line source can be approximated by the equation:

$$T - T_0 = q/(4\pi\lambda)\{d + \ln(t - t_0)\}, \quad \text{for } t < t_1,$$

where T is the temperature at time t, T_0 is the temperature at $t = 0$, q is the amount of heat produced per unit time and unit length of the line source, λ is the conductivity, d is a constant, and t_1 is the end of the heating period. The decrease of the temperature during the time of cooling can be approximated by the equation:

$$T - T_0 = q/(4\pi\lambda)\{d + \ln(t + t_0)\} - q/(4\pi\lambda)\{d + \ln(t - t_1 - t_0)\}, \quad \text{for } t > t_1.$$

For the thermal conductivity measurements, the infinite long line source can be approximated by a

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long, electrically heated wire enclosed in a cylindrical probe, and the temperature of the line source can be measured with a thermocouple or metal wire resistor placed next to the wire.

When the two probes with the same characteristics are introduced into material A (thermal conductivity λ_A) and material B (thermal conductivity λ_B), respectively, the ratio of the temperature rise of the two probes is represented by the equation:

$$\frac{T_A - T_0}{T_B - T_0} = \frac{q/(4\pi\lambda_A)\{d + \ln(t - t_0)\}}{q/(4\pi\lambda_B)\{d + \ln(t - t_0)\}} = \frac{\lambda_B}{\lambda_A}$$

where T_A and T_B are the temperature of the probe of A and B, respectively. The tangent of the locus of the temperature changes of both probes is the inverse ratio of the thermal conductivities of both the standard and measuring materials. If the thermal

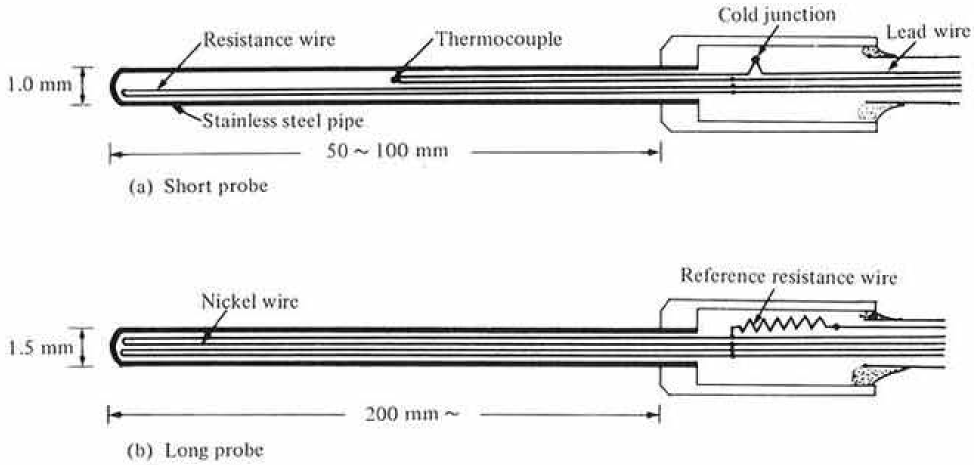

Fig. 1. Structure of heat probes

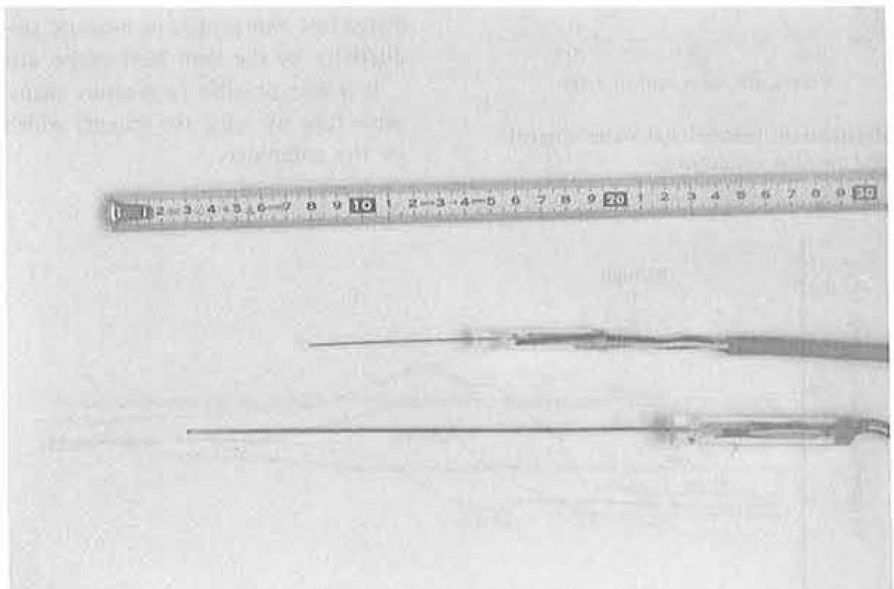

Plate 1. Heat probes

conductivity of the standard material is known, the thermal conductivity of the measuring material can be calculated by multiplying the value of the standard material and the ratio as follows:

$$\lambda_B = \lambda_A(T_A - T_0)/(T_B - T_0)$$

The decrease of the temperature of the two probes is also represented by the same equation.

2) Structure of the probe

The structure of the probe is shown in Fig. 1 and Plate 1. The temperature of the probe can be measured by two methods, one requiring the use of a thermocouple and the other requiring the use of a metal wire resistor. The former method can be used for a short probe and the latter for a long probe. As a long probe can measure the average thermal conductivity, the average soil water content can be determined[2].

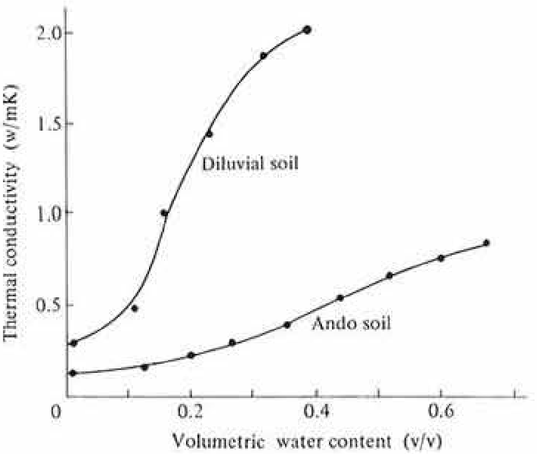

Fig. 2. Relationship between soil water content and thermal conductivity

Accuracy by this method mainly depends on the accuracy of the temperature measurement. One of the ways to increase the accuracy is to increase the temperature of the probe. However when the temperature increases, the soil water around the probe moves due to the heat generated from the probe. Therefore, the temperature increases by at most several degrees (centigrade) and the accuracy should reach a value of more than 1/500 of the temperature increase.

3) Structure of the system

This method was applied by using a microcomputer system. By switching on and off the electric current sent to the heater, the storage of the data on the temperature changes with time and the calculation can be performed by using a computer. As the data on the temperature change of the probe in the standard metarial can be stored in the memory of the computer beforehand, the ratio of the temperature change between the standard and the measuring material can be calculated by applying a self-correlation method. This computerized measuring system enabled us to use only one heat probe instead of two probes to measure the thermal conductivity by the twin heat probe method.

It is also possible to measure many points at the same time by using the scanner which is controlled by the computer.

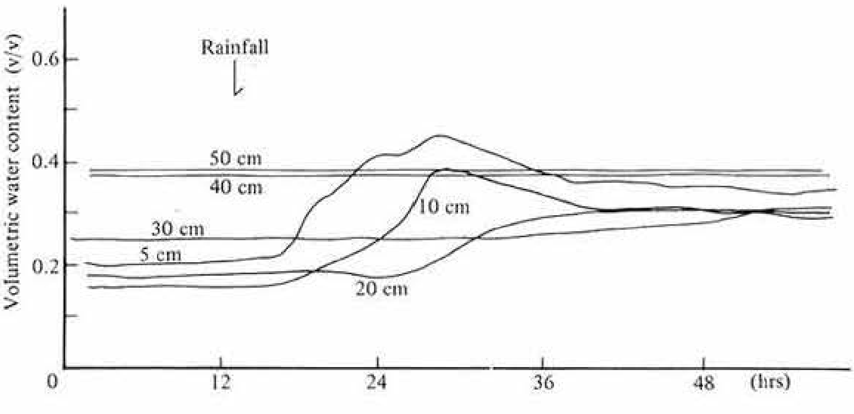

Fig. 3. Changes in soil water content after rainfall

This system can operate with a battery for more than one month and the data stored in the memory of the system can be collected by a handy computer through RS232C interface.

The system is currently being manufactured by two companies.

4) Measurement of soil water content in the field

The probes are fixed in the soil form the wall of a small pit in the field. After the setting, the pit is refilled carefully.

Results and discussion

Fig. 2 shows the relationship between the thermal conductivity and soil water contents measured in the laboratory. There was a linear relation in the range of the values of the field water content. Since the relationship between the thermal conductivity and soil water content varies with the kinds of soils, the conversion coefficient must be calculated for each soil type. To determine the conversion coefficients, it is recommended to take samples several times near the pit from each horizon where the probes are set up.

Since the thermal conductivity depends on the temperature of the soil, the thermal conductivity increases with the increase of the temperature. The changes in the thermal conductivity associated with the changes in the temperature amount to approximately a few percent for 10°C. However since the temperature changes in the soil are not very large, the error is not considerable in relation to the changes of the soil water content except for the soil layers near the soil surface.

Fig. 3 shows the changes of the soil water content measured by the method. The results indicate that this system can be used for the measurement of the soil water content in the field.

References

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