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Evaluation of Measurement Accuracy of *in-situ* Device for Measuring Soil Moisture Profiles in Arid Land

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Abstract: A medicinal plant called Licorice (*Glycyrrhiza*), which originally grows in arid lands, has been used for various purposes including herbal medicine. Recently, overharvest of Licorice has caused a problem of land deterioration and/or desertification, and some exporting countries have begun restricting the export of Licorice. To ensure a stable supply of Licorice, these study cultivation techniques of high quality Licorice are developed.

To cultivate Licorice, it is necessary to know soil properties in the site where wild Licorice grows. In this study, the fundamental characteristic of an *in situ* device that can measure moisture content of unsaturated ground over the ground water level was investigated. The device consists of a sensor probe, an access tube and a data acquisition device. Moisture distributions and its time-variations in a vertical direction can be obtained by pushing the access tube into the ground, followed by inserting the sensor probe in it. Sliding the sensor probe in the access tube allows us to measure the data at any point, and insertion/extraction of the sensor probe can be performed at anytime by leaving the access tube in the ground, indicating that this probe makes it possible to conduct a long-term monitoring of a continuous moisture profile.

As a result of accurate evaluation tests, it became clear that a calibration curve that is appropriate for sandy soil. This calibration curve was obtained by changing only the constant term in the calibration curve that is provided from the manufacturer of ADR sensor.

Key Words: ADR, Field survey, Licorice, Soil moisture

1. Introduction

It is said that 45 million (km^2) of the land are the desert ground, and, in addition, desertification progresses at the speed of 60,000 (km^2) every year now. Desertification is a serious problem in the global environment maintenance, and measures against desertification are pressing needs. An approach for the greening of desertification area has been conducted by Yasufuku *et al*. (2010) with a high additional value that uses a strong medicinal plant for arid land like the Licorice. Licorice (*Glycyrrhiza*), which originally grows in arid lands, has been used for various purposes including herbal medicine and sweetening ingredients. Recently, overharvest of Licorice has caused a problem of land deterioration and/or desertification, and some exporting countries have begun restricting the export of Licorice. To ensure a stable supply of Licorice, these study cultivation techniques of high quality Licorice are developed. Moreover, it is believed that this will lead to a countermeasure against desertification.

To cultivate Licorice, it is necessary to know soil properties in the site where wild Licorice grows. In this study, the fundamental characteristic of an *in situ* device that can measure moisture content of unsaturated ground was investigated.

2. Characteristics of ADR Sensor

The device consists of a sensor probe, an access tube and a data acquisition device as shown in **Figure 1**. Four moisture sensors, which can detect moisture content by means of the method of Amplitude Domain Reflectometry (ADR), are mounted in the sensor probe. Moisture distributions and its time-variations in a vertical direction can be obtained by pushing the access tube into the ground, followed by inserting the sensor probe in the access tube. Sliding the sensor probe in the access tube allows us to measure the data at any point. And insertion/extraction of the sensor probe can be performed at anytime by leaving the access tube in the ground. That is, this sensor prove makes it possible to conduct a long-term monitoring of a continuous moisture profile, where an image of the monitoring is schematically shown in **Figure 2**.

The ADR method is the one to measure the electrical resistance when shuttling by the signal of the high frequency of about 100 (MHz) that went out of two stainless rings pass

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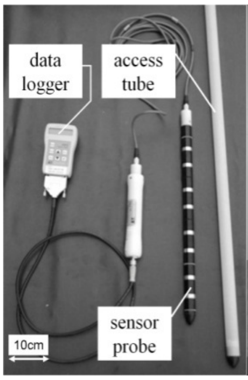

Fig. 1. ADR sensor. **Fig. 3. Calibration test.**

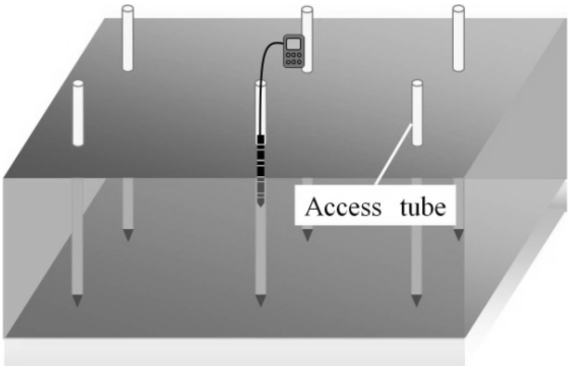

Fig. 2. Moisture profiling method.

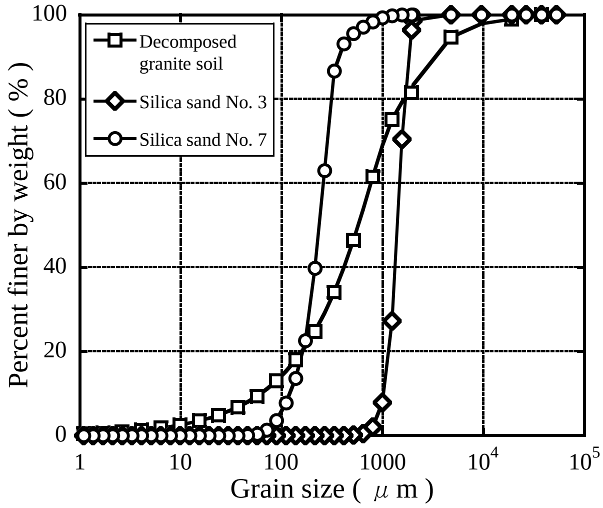

Fig. 4. Grain size distribution.

Table 1. Soil condition.

Sample	D_{50} (mm)	U_C	U_C'	w (%)	Height (cm)
Decomposed granite soil	0.60	13.3	1.9	0, 1, 3, 5, 7, 9, 11, 13, 15, 17, 20, 25	30
Silica sand No. 3	1.50	1.6	1.1		
Silica sand No. 7	0.25	2.1	1.1		

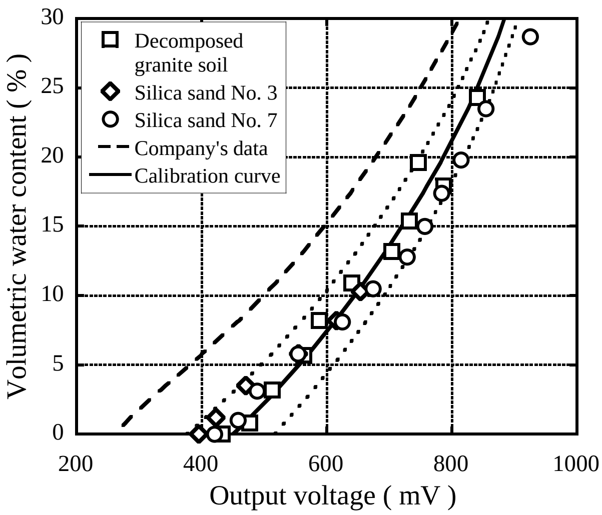

Fig. 5. Calibration curve.

through the soil. The electrical resistance depends on the permittivity of the material in the soil, and the permittivity is different according to each material. If the permittivity of air is assumed to be 1, the permittivity of the soil is about 4 and water is about 81. The measured permittivity is converted into the voltage, and the volumetric water content in the soil is calculated for the following polynomials;

$$\theta = -0.057 - 0.66V + 8.00V^2 - 27.91V^3 + 49.23V^4 - 42.46V^5 + 14.47V^6 \quad (m^3/m^3) \qquad (1)$$

Where θ is volumetric water content and V is voltage obtained. This equation is the calibration curve provided by the manufacture of the ADR sensor.

3. Evaluation of Moisture Profiling Method

3.1. Calibration

First, to use the ADR sensor in local soil ground, the accuracy of calibration needs to be examined. The examination was carried out in a column of 25.7 (cm) in the inside diameter and 30 (cm) in height shown in **Figure 3**. Decomposed granite soil, silica sand No. 3 (k - 3), and silica sand No. 7 (k - 7) were used as the calibration samples. Although a not less than 20 (kg) sample was needed for this calibration test, the sample collected by field survey was little. Therefore, this examination was carried out using Japanese sandy soil. The characteristic of grain size distribution and soil condition are shown in **Figure 4** and **Table 1,** respectively. These sample used are assumed as the sandy soil of the desert area where the investigation carried out. First, the sample that was used for adjusting the water content was packed into the column. Next, the part of a stainless ring of the ADR sensor is inserted in the central portion of the sample, and the output voltage is measured. After that, the sample is taken out, and water content is directly measured by The Japanese

Geotechnical Society (JGS) standards. Finally, the relation between the output voltage and the volumetric water content is formulated.

Figure 5 shows the relation between the output voltage and the volumetric water content. The calibration curve that is provided by the manufacturer of the ADR sensor is overestimating the volumetric water content about 5 ~ 10%. Therefore, it is necessary to obatain a new calibration curve that is appropriate for sandy soil. It is understood that there is a clear relation between the volumetric water content and the output voltage of each sample. That is, each plot is on the same curve, and this curve is expected to have a similar shape as the calibration curve provided by the manufacture. Then, the next expression is presented as a calibration curve that is appropriate for the sandy soil by moving Eq. (1) in parallel downward direction.

$$\theta = -0.1352 - 0.66V + 8.00V^2 - 27.91V^3 \\ +49.23V^4 - 42.46V^5 + 14.47V^6 \quad (m^3/m^3) \quad (2)$$

It is necessary for θ - intercept of Eq. (1) to be changed in order to move Eq. (1) in parallel downward direction. Therefore, Eq. (2) is characterized as an expression obtained by changing only the constant term of the Eq. (1) as a result of the data fitting. This expression is able to estimate volumetric water content more accurately for the sandy soil used in this study.

3.2. Application of ADR sensor to multi - layer ground

The calibration test was based on the single sample. However, it is thought that arid land has not only homogeneous ground but also heterogeneous ground which consists of various grain sizes. Therefore, in this examination, the ADR sensor was verified to confirm the moisture profile in the ground by making multi-layer ground as an approach to investigation on the heterogeneous ground.

The multi-layer ground of 2 (m) of height, where the heterogeneous ground on the arid land was imitated, is made shown in **Figure 6**. The samples k - 7 and silica sand No. 8 (k - 8) were used as model samples to prepare the laminated sandy ground shown in Figure 6, where depth of each layer was around 20 (cm). It is shown in Figure 6 that the order of the laminated layers are different from model A and model B. Water was supplied from the bottom after the earth tank was made, and the groundwater level was kept constant in the position of 10 (cm) from the bottom.

Figure 7 shows the water status from a water supply from the beginning to 21 hours to 240 hours (in 10 days) later. It is confirmed that the volumetric water content rises with the passage of time. Moreover, the volumetric water content rises in the layer of k - 8, and the change in the volumetric water content of the laminated ground is caught in the following water status. It can be seen that the precision of ADR sensor to each layer is high.

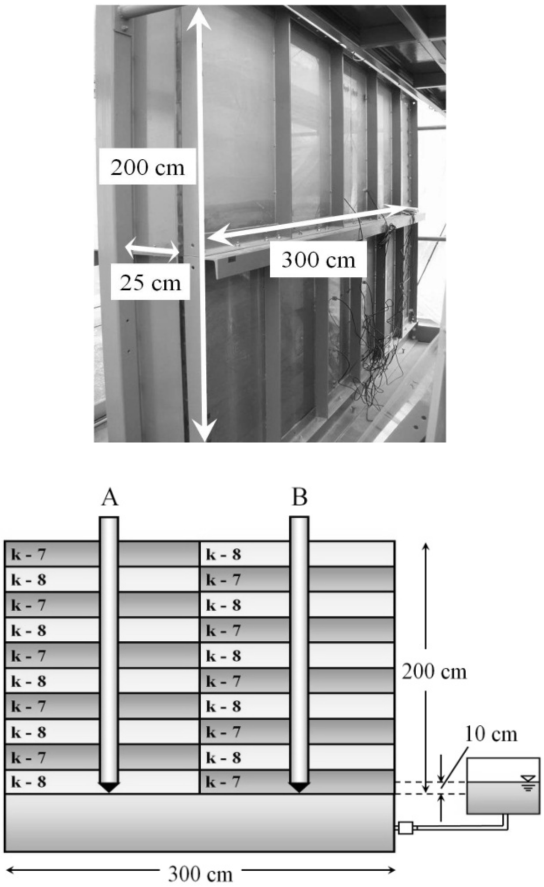

Fig. 6. Multi-layer tank.

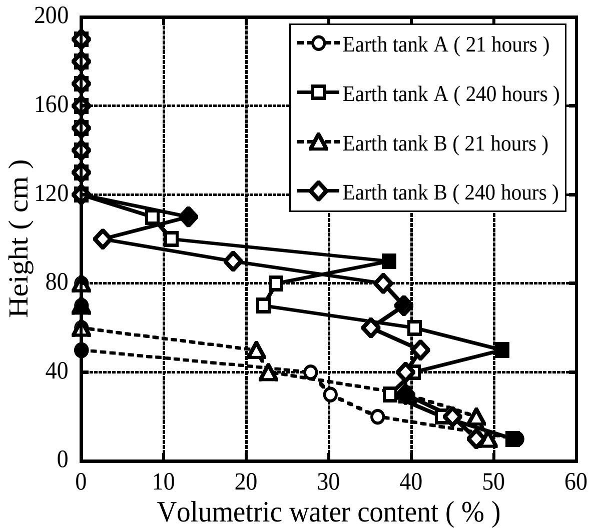

Fig. 7. Moisture condition. Black plots (●, ■, ▲, and ◆) are the layer of k - 8.

3.3. Determination of the calibration curve *in situ*

Although Japanese sandy soil was used for the calibration test as the arid land imitation, if this calibration curve is inapplicable, it is necessary to obtain a new calibration curve. In this section, reference was made about the proofreading method in a field survey by using the characteristic of the ADR sensor that it can obtain a new calibration curve by parallel translation.

It is shown that a new calibration curve is obtained when changing only the constant term in the calibration curve that is provided by the manufacturer of the ADR sensor. Then, the procedure to proofread *in situ* volumetric water content by using the sensor is shown below.

(1) The output voltage of the sensor in each depth is recorded at an original position.
(2) At some depth, undisturbed sample is collected, and the volumetric water content is requested to be directly measured through the laboratory experiments.
(3) The average of the difference of the volumetric water contents by a calibration curve provided by the manufacturer and the laboratory experiments is requested.
(4) It is assumed to be a new calibration curve for sum or difference between the average and constant term.

$$\theta = \alpha + f(V) \rightarrow \theta = \beta + f(V) \quad (m^3/m^3) \qquad (3)$$

Where α is constant value as shown in Eq. (1), and β is constant value that was obtained, shown in Eq. (2) for example, and f (V) is a function of output voltage. This work is an effective method in sandy soil, and application with different types of soils is future subject. If shapes of these calibration curves are similar to the calibration curve provided by the manufacture, application is possible.

4. Conclusions

(1) In this study, the calibration curve that is appropriate for sandy soil was obtained. This method is simple and consists of changing only the constant term of the calibration curve provided by the manufacturer. This expression reflects the change in the volumetric water content by the difference of samples in the multi-layer ground. That is, it is expected to be applied in a heterogeneous sandy soil.
(2) It was possible to measure the change of soil moisture with the passage of time. A lot of access tubes were set up on the investigation ground, the probe was inserted in every case at an arbitrary place, depth, and time. In this method, it is suggested that the moisture amount in a certain profile and the monitoring of the measurement in the direction of depth become simpler and economically feasible.

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