1. Research Paper

Experimental Set-up to Continuously Monitor Water Flow and Solute Transport in Unsaturated Large Weighing Lysimeters

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Summary

Current research focuses on soil conservation, crop irrigation scheduling and water quality control under drip irrigation systems for increasing water use efficiency. Of special interest is the measurement and prediction of water flow and solute transport in vadose zone in order to elucidate and control soil salinization. The overall objectives are to increase understanding of desertification processes in arid and semi-arid regions, to develop measures to control the desertification processes, and to improve irrigation methods for minimizing soil salinization. Effective soil and water management of irrigated fields requires knowledge of water flow and solute transport in soil. This includes salt accumulation in the top soil layer due to evapotranspiration when saline water from a shallow groundwater table, flow upward.

On June 1998, a monitoring system for water flow and solute transport under unsaturated condition was installed in large weighing lysimeters (798 mm in diameter and 1,200 mm in height) located in the Arid Land Dome. This new experimental facility was constructed to carry out experiments of water and solute transport. Volumetric soil water content, soil temperature, bulk soil electrical conductivity, and soil matric potential head of the large weighing lysimeters can be continuously measured using amplitude domain refrectometry sensors (ADR), thermocouple sensors, four-electrode salinity sensors, and electric tensiometers such as underground suction gauges (UNSUC), respectively. The characteristic of monitoring system for water flow and solute transport was described. The accuracy of the various sensors, the precision of electric balance, and the validity of the monitoring system are discussed.

Introduction

World population will increase to 8.6 billion in AD 2030. About 85 % of the population growth is taking place in developing countries. With the increase in population, enough food and fibers must be secured. However, over-pasturage, over-cultivation, a rise of subsurface water level by over-irrigation, soil erosion and salts accumulation in agricultural land may enhance desertification in arid and semi-arid regions, leading to social problems. The high potentiality of plant photosynthesis due to intense solar radiation in these regions may increase crop production if an appropriate cultivation and irrigation management system is practiced.

Under an appropriate manure management and solute concentration control in the root zone, a sustainable agricultural production system could be established. There are several research approaches to study salts accumulation reduction on a field scale. The main purpose of conducting research using weighing lysimeters is to fill up the gap between field and laboratory studies that are often problematic.

When salts accumulate on soil surface, leaching with low solute concentration water is an effective method for ensuring well-drained soils. The degree of leaching depends on the salt tolerance level of the crop at each growing stage and the relationship between concentration of soluble salts in soil solution and crops yield. It is necessary therefore to establish a soil and water management practice that will be appropriate for any specific condition. For this purpose, it is important to establish the relation between crop yield and solute concentration of soil water, as well as improving water use efficiency and soil permeability. Soil water content and electrolyte concentration of soil solution in the crop root zone need to be managed adequately. It is difficult to measure water and salt distribution in a tilled soil layer and lower layers of a field. For this practical purpose, it is necessary to develop an effective high precision sensor for water content and solute concentration measurements under field conditions. The weighing lysimeter can be used for this purpose.

In order to establish suitable water flow and solute transport for a given soil, there is a need to measure simultaneously water flow and solute transport in undisturbed soil using four-electrode sensors and tensiometers with pressure transducer. Because the four-electrode sensor response depends on soil water content, solute concentration and temperature, the soil water content should be measured independent by the solute concentration[7)]. It is well known that the amplitude domain refrectometry sensors (ADR) have only small errors in measuring water content and are affected very little by the solute concentration[8)]. Because solute transport depends mainly on convection flow of the soil water movement, it is necessary to determine the water potential gradient between two locations at high precision. In order to minimize measurement errors by air temperature changes, underground type of electric tensiometer has been developed[5)]. Therefore, sophisticated systems have been installed in order to monitor water flow and solute transport.

Monitoring system for water flow and solute transport

This device measures water and solute transport in the vadose zone of a large-sized weighing lysimeter. The device can be used also to monitor the three-dimensional solute transport in the root zone under vegetation. When a sensor at a given depth is missing, a stopcock made of polyvinyl chloride is inserted instead. When a chemical composition of soil solution is needed, a soil solution extraction sampler (Rhizon soil water sampler made by Eijkelkamp Company in the Netherlands) can be used. Cations and anions in extracted solution are analyzed using an atomic absorption flame emission spectrophotometer and an ion chromatograph, respectively. Crop roots can be separated from soil using a root washing device (RWB made by Delta-T Company of the United Kingdom) which is part of the system.

The major components of this system are as follows: ① Three weighing lysimeters with controlled water level, or three gravitational drainage type weighing lysimeters, ② Four weighing lysimeters with controlled suction system at the bottom of soil column, ③ A large undisturbed soil core sampling device and ④ Portable devices for soil water content and salinity determination.

1. Weighing lysimeters with controlled water level

(1) Constant groundwater level system

The following studies will be carried out : “Solute movement in soil due to water evaporation from soil surface in a large-sized cylindrical column with constant shallow groundwater level”, “Simultaneous water flow and solute transport and salt accumulation process under constant groundwater level condition", "Relation between groundwater level and water logging", and "Relation between plant salt stress and groundwater salinity".

Inter-relationship between soil type, groundwater level, solute concentration of groundwater, crop type, and growing stage will be studied. Salt accumulation phenomenon takes place when constant shallow groundwater level exists. Variation of water flow and solute transport due to evaporation from bare soil and transpiration from plants will be measured as a function of time. Groundwater level can be established at any depth such as 20, 30, 40 cm, down to 100 cm from soil surface. Groundwater level can be controlled at any water level in a precision of ±1 cm, and the variation of ground-water level during the experiment can be monitored automatically. The poly-vinyl chloride column of the lysimeter was constructed by three segments of 79.8 cm inside diameter and 40 cm height each as shown in . Water content, electrolyte concentration, root length and root weight can be determined simultaneously in this column at the end of the experiments by direct sampling.

Three sets of sensors can be installed around the lysimeter at depths of 10, 20, 30, 50, 70, and 100 cm from soil surface. Three-dimensional distribution variation of water content and salinity in soil with time can be determined. The following sensors will be used : ① ADR soil water sensors - to measure volumetric water content, ② Electric tensiometers - to measure soil matric potential head, ③ Four-electrode salinity sensors - to measure soil bulk electrical conductivity in relation to soil water content, solute concentration of soil solution and soil temperature, ④ Thermocouples - to measure soil temperature, ⑤ Soil solution extraction samplers - for ion composition, electrical conductivity and pH determinations, ⑥ Matric potential sensors which are set at the depth of 10 cm from soil surface - to measure soil water potential at low soil water content range.

The sensor center has been installed at a distance of 25 cm from the column center. The filter at the bottom of the soil column consists of three kinds of stainless steel screens. The purpose of this filter is to prevent downward flow of soil particles. The electric tensiometer is installed at the upper part of the filter to measure soil matric potential head on it. The bottom boundary condition of the soil column can be monitored using the electric tensiometer; the underground suction gauge (UNSUC[2)]). These measurements can be utilized for the boundary condition in numerical models for simulation purposes. Assuming maximum evapotranspiration of 0.83 mm/ h, a constant flow rate of saline water of 420 mL/h is automatically supplied from a water reservoir tank of 20 L capacity. A constant groundwater level is maintained using a pressure gauge and electromagnetic valve with accuracy ±3mm. The water flow from the water reservoir tank can be measured at 1 % precision, using electromagnetic current meter.

(2) Gravitational drainage system

The following studies will be carried out: "Leaching effect on salt accumulation", "Simultaneous water flow and solute transport during the leaching process", "Salinity effect on plant development and yield under irrigation with saline water", "Salt balance under saline water irrigation and three dimensional salt and water dynamic distribution in soil". Inter-relationship between soil type, water salinity and plant type at various growing stages will be studied.

The cross section of this device is fundamentally similar to that of the weighing lysimeter with controlled groundwater level (Fig. 1). When the electromagnetic valve connecting the stilling well to the column is close and the electromagnetic valve connecting the tank for measuring drainage component to the column is open, gravitational drainage takes place. These automatic electromagnetic valves can be operated manually using a touch-panel.

Irrigation water and leaching fraction of low solute concentration can be supplied to the soil in the column for studying removal of salt accumulation on soil surface and decrease of solute concentration at a given depth in the soil. The amount of the drainage water is determined in the drainage tank using an electronic balance. Variation in electrical conductivity of drainage water is determined with time using an electrical conductivity gauge. Effect of leaching on yield can be quantitatively evaluated by measuring solute transport during the leaching process. Long term effects of salinity on growth and yield of fruit trees, can be studied as well using this system.

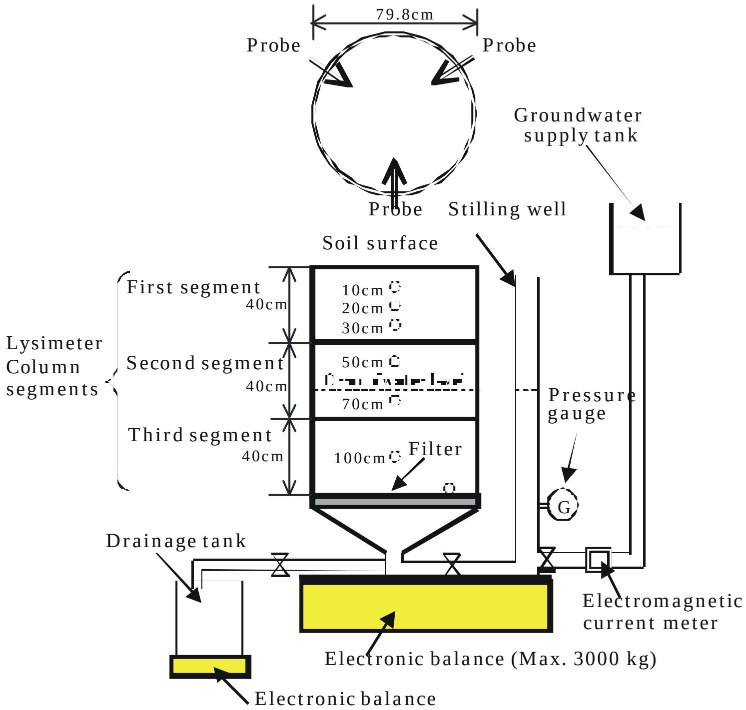


Fig.1. A schematic cross section of weighing lysimeter with controlled groundwater level.

2. Weighing lysimeters with controlled suction system located at the bottom of soil column

The following studies will be carried out : "Solute transport during evaporation from soil surface in large-sized cylinder with deep groundwater level", "Simultaneous water flow and solute transport in soil and salt accumulation process under evapotranspiration", "Evapotranspiration changes due to salt accumulation and crust formation at the soil surface", "Variations of solute concentration in the root zone under saline water irrigation", "Effects of pore water velocity on physical dispersion coefficient", "Simultaneous water flow and solute transport under soil reclamation", "Establishment of suitable irrigation scheduling under saline conditions".

In case of a deeper groundwater level, water flow can be controlled by constant negative pressure at the bottom of soil column. Irrigation and drainage dynamics will be measured during the growing season. For example, a negative pressure head of –200 cm depth will be exerted at the depth of 115cm from soil surface to maintain the condition of the deeper groundwater. Similar irrigation conditions prevail in cultivated fields.

When a gravitational drainage type weighing lysimeter has been used, water accumulates in the bottom of the soil column, and the upper part of the filter at the bottom becomes moist. On the contrary, when the weighing lysimeter is controlled by a suction system, drainage can be promoted to simulate field conditions under deep groundwater. Salt balance can be evaluated by measuring solute concentration in the irrigation water, drainage water and in the soil solution.

The hydrodynamic dispersion coefficient used for solute transport calculation can be obtained by measuring the solute concentration in percolation as a function of time by changing two known different solute concentrations at steady state water flow. The small rainfall simulator (Fig. 2) can be used to maintain steady state flow. The rainfall intensity can be varied from 5 mL per minute (equivalent to 0.6 mm/h) to a maximum of 60 mL per minute (equivalent to 7.2 mm/h). A steady state water flow can be maintained, and two solute concentrations (CON1, CON2) can be inter-changed instantly. Thus, hydrodynamic dispersion coefficient of the soil can be evaluated. The solute concentrations in soil can be determined using four-electrode probes, ADR water sensors, and temperature sensors at the depth of 10, 20, 30, 50, and 70 cm. The actual electrical conductivity of the soil (ECa) is determined by four-electrode probes as a function of soil water content (θ), soil temperature (T) and electrical conductivity of soil solution (ECw)[3]. The solute concentration(C) at each depth can be obtained using the four-electrode calibration curve (C = f(ECw) = f(ECa, θ, T)) for each soil.

Small quantity and high frequency irrigation is obtained using a drip irrigation or micro-irrigation method in the weighing lysimeters. The maximum irrigation intensity of the irrigation system is about 7 mL per minute (equivalent to a flux of 0.023cm/s), and the solute concentration in irrigation water can be determined. The soil water content in crop root zone is controlled by irrigation management, whereas the soil matric potential is kept at value greater than -850 cm head at the depth of 20 cm from soil surface. Under such conditions a drainage rate of 420 mL h^{-1} is obtained when the average irrigation rate is 0.83 mm h^{-1} under steady state water flow. Because the capacity of the drainage container is 50 L, it is expected that it will take 5 days to fill. The upper and lower level of the drainage container can be controlled. An electro-magnetic valve controls the water level in this container. The discharge of the drainage can be recorded automatically.

One of the problems in a drainage type weighing lysimeter is clogging of the filter. Because the pressure in the filter is negative, dissolved air is present in the water. The existence of air bubbles under the filter reduces the cross-section area of water flux. The stainless steel mesh on the ceramic filter prevents silt size particles from passing through. Air entry value of the ceramic filter is less than -300 cm water head, and air bubbles do not accumulate in the lower part of filter. When drainage is stopped

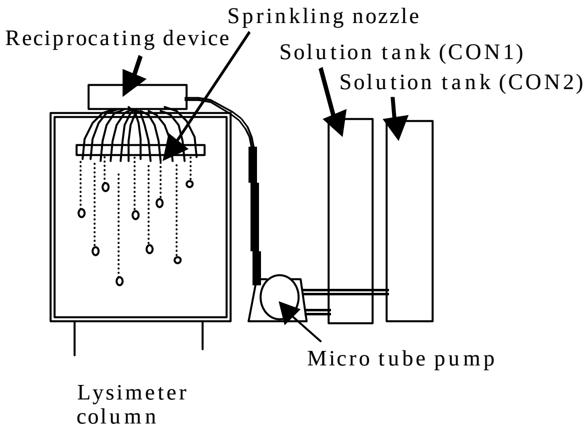
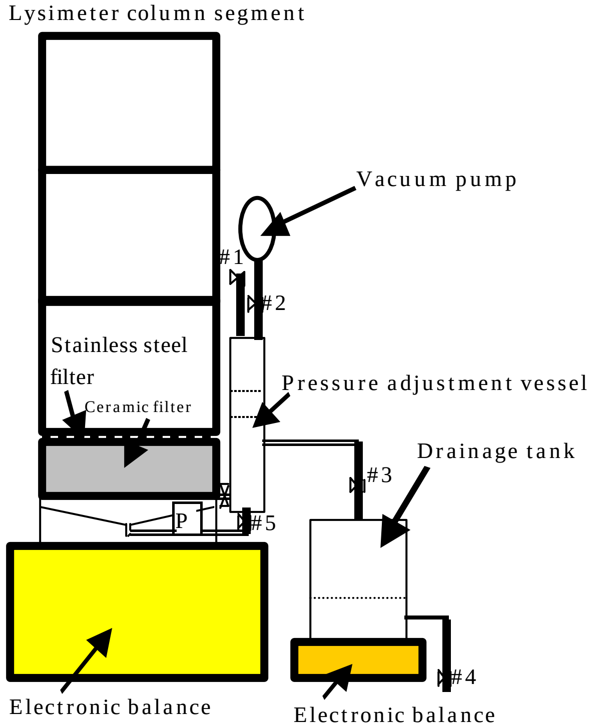


Fig.2 A schematic cross section of the small rainfall simulator.



Where, P : Circulating pump, #1 : electromagnetic valve connecting to the atmosphere for adjusting the pressure in the vessel, #2 : electromagnetic valve connecting the pressure adjustment vessel and vacuum pump, #3 : electromagnetic valve for controlling outflow from the pressure adjustment vessel, #4 : electromagnetic valve for controlling outflow from the drainage tank, #5 : electromagnetic valve between the pressure adjustment vessel and the lysimeter column.

Fig.3. A cross section of weighing lysimeter with controlled suction at the bottom of soil column.

temporarily, the air present in the lower part of filter is removed by circulating water of the same quality through the filter by a pump, keeping the filter always saturated.

Soil water pressure head on the filter can be controlled automatically. The electromagnetic valve (#3) for controlling outflow from the pressure adjustment vessel to the drainage tank, the electromagnetic valve (#1) connecting to the atmosphere for adjusting the pressure in the vessel, the electromagnetic valve (#2) connecting the pressure adjustment vessel and the vacuum pump, and the electromagnetic valve (#5) between the pressure adjustment vessel and the lysimeter column are shown in Fig. 3. The soil water pressure head at the bottom of the column and the drainage discharge are automatically controlled and measured. Soil water pressure head on the filter can be reduced using a vacuum pump. In other words, when the water level in the pressure adjustment vessel exceeds a fixed upper level, the electromagnetic valves (#5) and (#2) are closed, and the pressure in the pressure adjustment vessel equilibrated with the atmospheric pressure by opening the electromagnetic valves (#1) and (#3) while draining the vessel. When water level in the vessel is lower than a fixed second level, the electromagnetic valves (#3) and (#1) are closed and (#2) is opened, and then pressure head in the pressure adjustment vessel increases to the negative pressure setting. The electromagnetic valve (#5) is then opened, and therefore soil water pressure head on the filter does not change.

Measurement system and characteristics of sensors

Independent measurements can be carried out simultaneously by using three weighing lysimeters of either constant water level or three gravitational drainage type and four weighing lysimeters with controlled suction at the bottom of soil column. Three weighing lysimeters with constant water level or three gravitational drainage type weighing lysimeters are set up in the Arid Land Dome, which is 15 meters high and 36 meters in diameter.

The variations of output values using ADR water sensors, electric tensiometers, temperature sensors, four-electrode sensors, electronic balance, and electrical conductivity gauge of drainage are all recorded automatically. By connecting the system to Internet, it is possible to transfer experiment data to any desired e-mail address. Each measurement interval can be set up from 1 minute to a maximum of 24 hours. Usually, the interval between measurements is 10 or 15 minutes.

1. Weighing lysimeter with constant groundwater level or gravitational drainage

Each lysimeter contains 15 moisture sensor positions, 13 electric tensiometer positions (including a position at the bottom of the column), 15 temperature sensor positions, 15 salt sensor positions, and 3 matric potential sensors positions. All these sensors are connected to a data-recorder. Output data on the cumulative weight of lysimeter column segment, the cumulative weight of the drainage tank, the electrical conductivity of the drainage water, the cumulative water volume from the groundwater supply tank to the column, and the groundwater level as shown in Fig.1 can be measured using a large electronic balance (max 3000kg), an electronic balance (max 60kg), electrical conductivity gauge, an electromagnetic current meter, and pressure transducer respectively. These data can be stored in the same data-recorder.

2. Weighing lysimeter with controlled suction at the bottom of soil column

Each lysimeter contains 18 moisture sensor positions, 13 electric tensiometer positions (including a position at the bottom of the column), 18 temperature sensor positions, and 18 salt sensor positions available. All these sensors are connected to another data-recorder. Output data on the cumulative weight of lysimeter column segment, the cumulative weight of the drainage tank, and the electrical conductivity of the drainage water as shown in Fig.3 can be measured using a large electronic balance (max 3000kg), an electronic balance (max 60kg), electrical conductivity gauge, respectively. The pressure head in the pressure adjustment vessel and the cumulative water discharge from two irrigation containers can also be recorded by measuring with a pressure transducer and two electromagnetic current meters respectively.

Data of one day can be saved by the csv-form of MS-Excel in a personal computer under Windows NT.

3. Moisture sensor (ADR water sensor)

Neutron moisture gauge or gamma ray attenuation density probe is used for measurement of soil water content in the field. As a method to measure dielectric constant of the soil, high quality gauge of TDR (Time Domain Refrectometry) method, FDR (Frequency Domain Refrectometry) method, ADR (Amplitude Domain Refrectometry) method, and electromagnetic wave methods are commercially available. Whereas the TDR and the FDR systems include expensive oscilloscope and spectrum analyzer, respectively, ADR system is simple and not expensive. The ADR water sensor that has similar measurement precision as TDR method was selected[9]. Dune sand was used for calibration of ADR water sensors (Fig. 4).

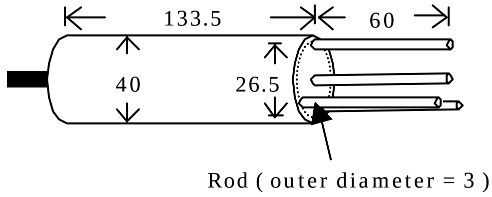


Fig.4. ADR water sensor (dimensions in mm)

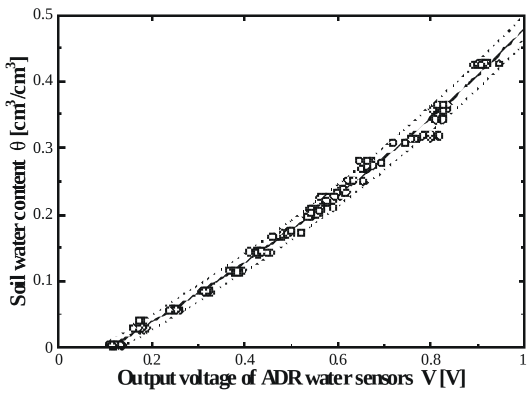


Fig.5. Measurement precision of water content using ADR water sensors.

The relation between volumetric water content of soil and voltage output from ADR sensor (Delta-T company, ML-1 of the United Kingdom) was studied. In order to obtain a desired soil water content, water amount of 40, 80, 120, 160, 200, 240, 280, 320,360, 380, and 400 g was added respectively in each vinyl bag with 1600g dry Tottori dune sand, mixed well, and packed uniformly in a column of 10 cm in inside diameter and 15 cm high to a volume of 1 L. The calibration results using 14 probes of ADR water sensors are shown in .

Calibration data from 14 probes of ADR water sensors are used to obtain equation (1).

$$\theta = 0.0699\ V^3 + 0.0564\ V^2 + 0.395\ V - 0.044 \quad \ldots \quad (1)$$

where, θ is volumetric water content, and V is the output voltage. The standard error for estimation was 0.0088 cm^3/cm^3. In other words, the precision is less than 0.01 cm^3/cm^3.

The effect of solute concentration on water content measurement was tested. The sodium chloride concentration in solution was 0, 500, 1000, 2000, and 5000 mg L^{-1}. The output voltage values of ADR water sensor as a function of NaCl concentration are shown in Fig. 6.[8]

Influence of solute concentration on water content measurement using ADR water sensors depends on the degree of soil water content. It was observed that soil water content, in the range of water content higher than 0.2 cm^3/cm^3 were underestimated to a maximum value of 0.03 cm^3/cm^3 due to solute concentration. Soil water content shortly after irrigation is less than 0.15 cm^3/cm^3 in sandy field. These results indicate that the effect of solute concentration on water content measurement using ADR water sensor can be neglected[8].

Therefore, 15 probes of ADR water sensors were installed in the column No.3 (constant groundwater level) and calibration experiments were carried out for estimating the measurement error. Dry sand and given amount of water were mixed in a polypropylene bag to obtain soil water content of 3, 5, 8.5, 10% by weight. The ADR water sensor in this system is operated on direct current of 10 V. The Output voltage (V) is recorded by precision of 0.25 mV. At the spot where the water sensor was inserted, core sampling of 50mL was done, and volumetric water content (θ) was estimated by the oven dry method. Relation between output voltage (V) and volumetric water content (θ) is given in Fig. 7. These results were compared with the calibration curve of equation (1). The error of each ADR water sensor was determined. It was found that the maximum measuring error was less than 0.02 cm^3/cm^3 when 15 probes of ADR water sensors were used for the calibration curve (equation 1). To increase the precision, individual calibration of ADR water sensor is needed.

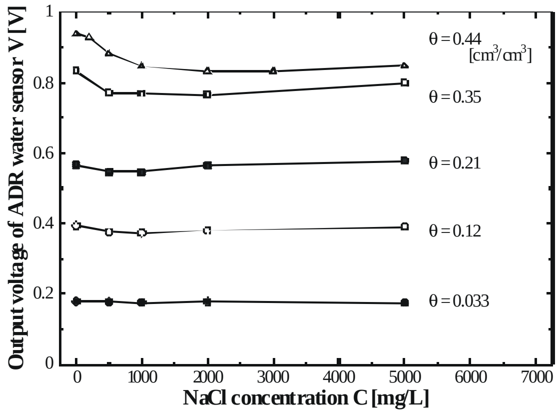


Fig.6. Influence of salt on ADR water sensor.

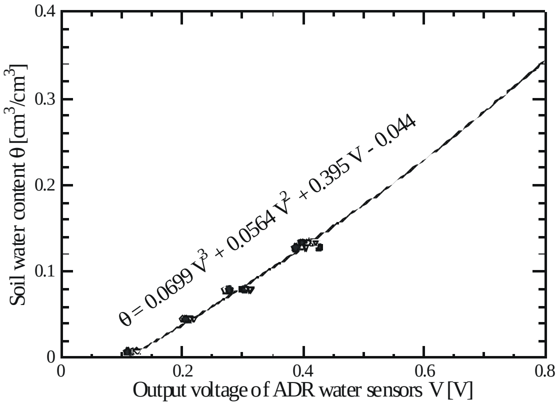


Fig.7. Calibration curve of ADR water sensor.

4. Electric tensiometer (UNSUC)

Tensiometers are used to determine soil matric potential head and hydraulic gradient. Due to air accumulation in the upper part of the tensiometer, temperature variation affects the matric potential head measurement[5]. Thus, a new electric tensiometer system was developed by setting the pressure transducer inside the porous ceramic cup, in order to reduce the temperature impact[2].

The electric tensiometers (SK-5000ET, brand name UNSUC[2]) made by Sankei-rika Company, Tokyo in Japan), were connected to the atmosphere through a tube (Fig. 8-②). The calibration curve of these electric tensiometers was examined in the range 0- 200 cm pressure

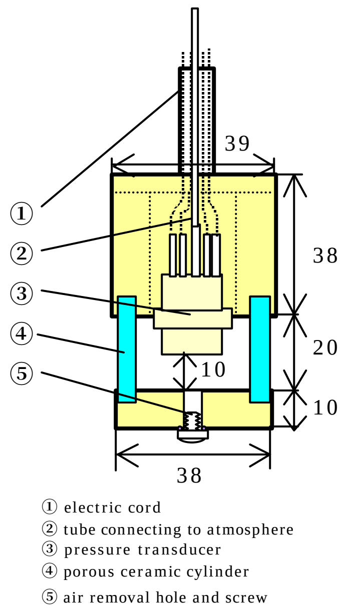


Fig.8. Electric tensiometer (dimensions in mm)

head. Relation between output voltage (V) and matric potential head (h) of the soil water was examined.

$$\left.\begin{aligned} h &= -20.6\,V - 6.1 \\ h &= -20.4\,V + 46.1 \\ h &= -20.6\,V + 28.0 \end{aligned}\right\} \text{------------} \quad (2)$$

The calibration curves for the three electric tensiometers of column No.3 in the weighing lysimeter with a constant water level are shown in Fig.9.

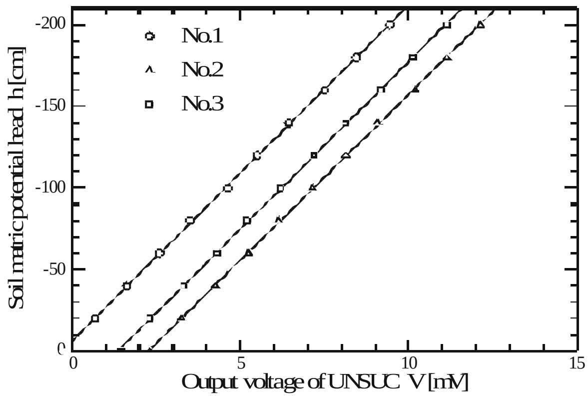


Fig.9. Calibration curve of electric tensiometers.

The correlation coefficient is higher than 0.9999 and the standard error for estimation is 1 cm or less. It means that the precision of measurement is less than 1 cm head. The precision of other systems such as data-recorder, and voltage power supply are important for keeping high experimental precision. Calibration is also necessary for individual electric tensiometers. A calibration box made up of eight probes was developed for calibration experiment as well as for air degasification in the porous cup of the tensiometer prior to calibration.

5. Soil temperature and salinity sensors (Four-electrode sensor)

In monitoring water flow and solute transport, a four-electrode sensor with a thermocouple type soil temperature sensor was used. A power supply of high frequency was connected to the outer two electrodes, and the voltage between the two inner electrodes was measured as shown in Fig.10. Output value, Lt, is the ratio, V1/V2, of the voltage (V1) between both ends of the 1 kΩ resistance in the outer electrode circuit to the voltage (V2) between the two inner electrodes[3),4)]. Electrical resistance value between the electrodes was measured and the electrical conductance, which is the reciprocal of electrical resistance, was calculated.

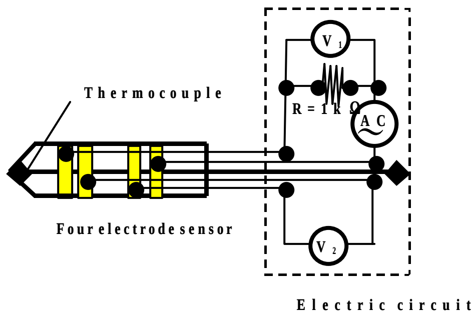


Fig.10. Soil temperature and four-electrode sensor.

Calibration of the four-electrode sensor is necessary for the soil solute concentration estimation. This calibration can be done with electrolyte solution at various solute concentrations[6)].

The four-electrode sensor shape factor was examined using different NaCl solutions concentration of 0, 500, 1000, 2000, 5000, 10000 mg L^{-1} (Electrical conductivity, ECw, of these solution was 0.0042, 0.968, 1.893, 3.68, 8.52, 16.21 dS/m, respectively). The calibration curves for three sensors (out of 15) were as follows:

$$\left.\begin{aligned} &1.\ ECw=0.205(Lt/1000)-0.036 \\ &2.\ ECw=0.197(Lt/1000)+0.001 \\ &3.\ ECw=0.201(Lt/1000)-0.023 \end{aligned}\right\} \text{--------} \quad (3)$$

The correlation coefficient for each sensor was greater than 0.9999 and the standard error for estimation was 0.0545 dS/m. From the above-mentioned results, the bulk soil electrical conductivity

(ECa) can be calculated by using the equation

ECa = α (Lt/1000), where, α is the sensor coefficient. The α coefficients for sensors 1, 2 and 3 are 0.205, 0.197, 0.201, respectively.

Relationships between ECa and ECw for the salt solution extracted from saturated soil were examined. For the saturated condition, 10 kg of dry sand were put in an airtight container of 9.5 L, and NaCl solutions of 0, 200, 500,1000, 2000, 3000, 7000, 10000, 30000 mg L^{-1} were added up to 1 cm above sand surface. For the unsaturated condition (10 % water content), 200 mL of NaCl solution of 0, 500, 1000, 10000, 30000 mg L^{-1} were added to 10 kg of dry sand, in an airtight container of 9.5 L, and mixed homogeneously.

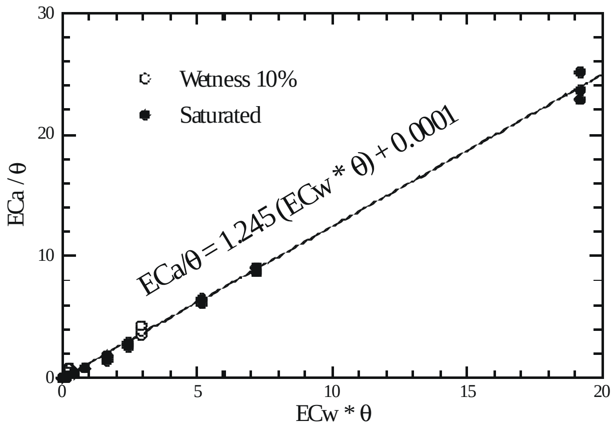


Fig. 11. Calibration of four-electrode sensors for dune sand

ECa, ECw/θ, ECa/θ were calculated from experimental data from saturated and unsaturated sand and the results are shown in . Calibration curve of the four-electrode sensor for dune sand can be calculated using the following equation[3]:

$$ECa/\theta = A\,(ECw \cdot \theta) + B \qquad ..... (4)$$

Ignoring B and assuming A = 1.245, the electrical conductivity (ECw) of the soil solution can be calculated using the following equation:

$$ECw = ECa \,/\, (1.245\,\theta^2) \qquad ..... (5)$$

The ECa values obtained from the four electrode sensors were plotted versus the solution EC (Fig.12). The solid line in this figure shows a slope of 1 to 1 ratio, and the dashed line in Fig.12 means a deviation of 5 %. The using output value (Lt) of a four-electrode sensor, volumetric water content (θ) of ADR water sensor, and calibration curve of equation (5), the electrical conductivity of soil solution can be estimated within an error range of 5 %.

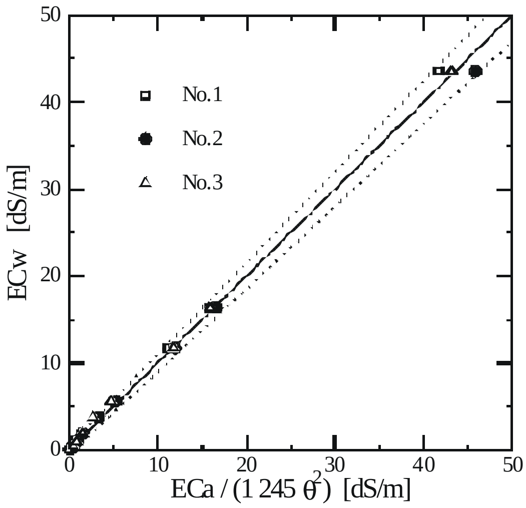


Fig.12 Measurement precision of electrical conductivity ECw using four-electrode sensors.

6. Matric potential sensor

Tensiometers cannot be used when soil water content is low, and the matric

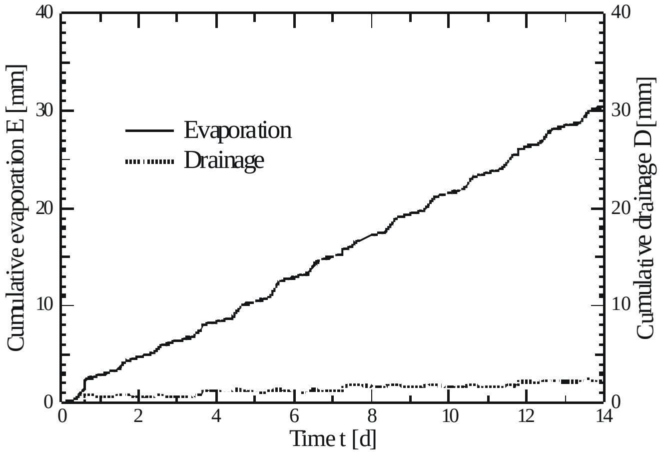


Fig.13. Cumulative evaporation and cumulative drainage measured by electronic balances.

potential head is less than -1000cm. However, matric potential sensor made by Campbell Company can be used to determine water potential at values lower than -1000 cm[10]. This type of sensor is installed in this system.

7. The weight measurement

A large electronic balance of the maximum load 3000 kg with 50g resolution is used in this lysimeter. This means that weight change due to evaporation and evapotranspiration can be detected with a precision of 0.1 mm, because the horizontal cross section area of the column is 5000 cm^2. Drainage can be measured using an electronic balance with maximum load of 60 kg and a 20g resolution. Thus drainage can be measured with a precision of 0.04 mm.

The column in the weighing lysimeter with controlled suction system at the bottom was packed with Masa soil. An experiment on bare Masa soil was conducted on October 1997 when the matric potential head on the filter changed to -200 cm. The cumulative evaporation (E) from soil surface and the cumulative drainage (D) are shown in Fig.13. It is recognized that cumulative drainage component of two weeks is around 2 mm. On the other hand, it is also recognized that the average daily soil evaporation is 2.1 mm.

Large undisturbed soil core sampling device

A modified large-sized undisturbed soil core sampling device (developed in the Netherlands[1)]) was used to obtain undis-turbed soil core. The device consists of heavy-duty steel components to press soil core cylinders into the soil. The description of this devices given is given in Fig.14.

The procedure of taking an undis-turbed soil core is as follows.

①Assembling the parts of the polyvinyl chloride (PVC) cylinder (Fig.14a).

②Placing the cylinder with the sup-porting device on soil and connecting it to the above H-shaped steel beam.

③Setting the hydraulic ram between the cylinder and H-shaped steel beam. (Fig.14b)

④Pressing the cylinder into the soil using the ram.

⑤Removing the soil around the cylinder.

⑥Disconnecting the soil core from the bulk of the soil using the cutting plate and the hydraulic ram (Fig.14c).

Soil core samples of 40 cm long and

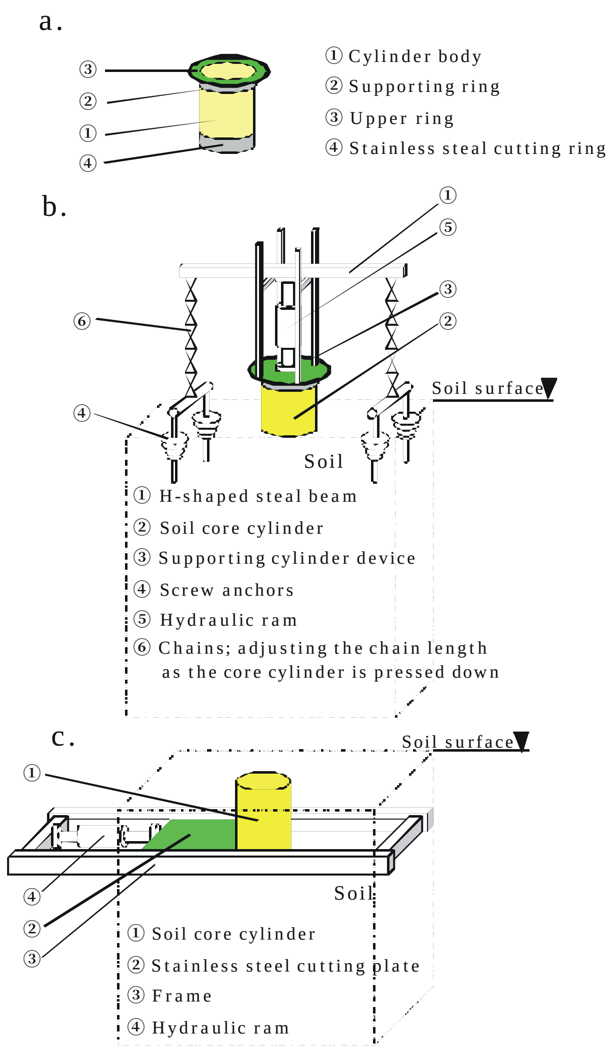


Fig.14. Large undisturbed soil core sampling device.

20, 30, 40, and 50 cm in diameter were transferred to the lysimeter for studying simultaneous water flow and solute transport.

Portable soil water and salinity measuring set

A water dielectric constant indicator, with precision similar to the TDR method, was developed. A portable soil water and salinity measuring set shows the volumetric water content and the solute concentration values on a liquid crystal (TRIME-FM, modified P2-probe made by TRIME Company of Germany).

In order to determine the measurement precision of the TRIME modified P2-probe sensor, various volumes of electrolyte solution at a given concentration were added to a given amount of dry sand to obtain water contents of 3, 6, 9, 12, 15, 18 and 21 % and saturation. Then, volumetric water content and dry bulk density were determined by sampling the soil with a core sampler of 50 mL. The relationship between water content data determined by soil water sensor (TRIME P2-probe) and water content determined by core sampling of 50 mL is shown in Fig.15. The dry bulk density of the sand was 1.55 g/cm^3.

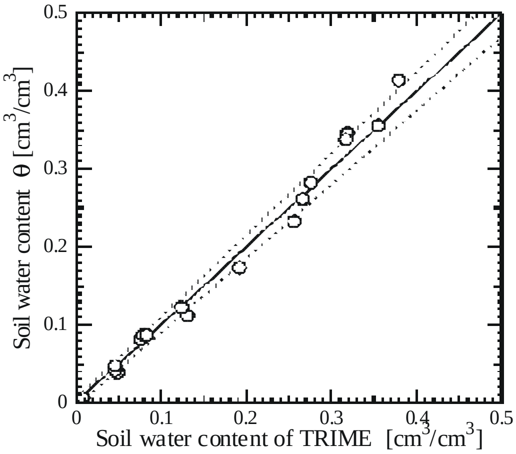


Fig.15. Measurement precision of water content using a portable soil water and salinity measurement set.

Soil water content lower than 0.2 cm^3/cm^3 can be measured within a precision of 0.01 cm^3/cm^3 using soil TRIME P2-probe. Soil water contents in the ranges of 0.2 - 0.3 and 0.3 - 0.4 cm^3/cm^3 are overestimated and underestimated by 0.02 cm^3/cm^3, respectively. Thus, in general, experimental data can be measured with a relative error of 5 % as shown by the dashed line of Fig.15.

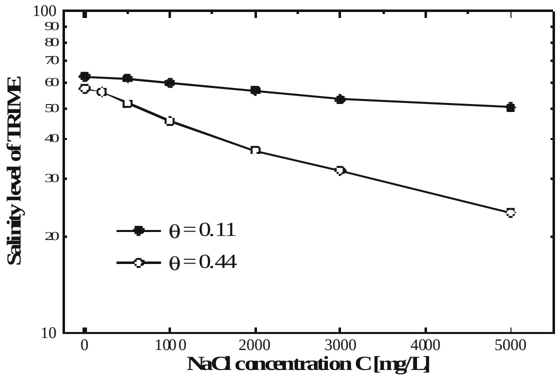


Fig.16. Relationship between NaCl concentration and salinity level measured by the portable soil water and salinity measuring set.

NaCl concentration of 0, 200, 500, 1000, 2000, 3000, 5000 mg/L were used for calibration. The volumetric water content was adjusted to 0.11 cm^3/cm^3. Saturated sand is also used in the calibration experiment. Relation between salinity level measured by the portable soil water and salinity measuring set and the NaCl concentration is shown in Fig.16. The salinity level decreases as the solute concentration increases. Salinity level however, depends on soil water content and electrolyte concentration in soil solution. From practical point of view, it is necessary

Fig.17. Lysimeter column segment and a large-sized electronic balance.

to estimate the electrical conductivity of soil solution from the measured salinity level.

Conclusion

In arid and semi-arid lands, salt is accumulated on the soil surface by capillary rise from shallow groundwater level due to evaporation during the dry season. Groundwater level rises due to over-irrigation in poor drainage situations. Salt accumulation by capillary rise is usually associated with waterlogging phenomenon. On the other hand, leaching the soil by relatively high quality water is done in order to remove salt from the soil root zone, when drainage conditions prevail. Such phenomena can be explained by simultaneous water flow and solute transport during infiltration, drainage, redistribution, and evaporation processes. This research paper shows the need for monitoring system for water flow and solute transport (Fig.17). The monitoring system for water flow and solute transport, in which fundamental studies can be carried out, has been built at the Arid Land Research Center.

This system was constructed by Yamatake Company (Yokohama), Fujiyama Company (Kagoshima), Sankei Rika Company (Tokyo), and Daiki Rika Company (Tokyo).

Acknowledgements

We wish to thank Dr. Masaki Tominaga of National Research Institute for Earth Science and Disaster Prevention for his valuable comments on this paper. The authors are grateful to Dr. Rami Keren who is a visiting professor at the Arid Land Research Center (ALRC) of Tottori University for improving the original manuscript.

References

1) de Rooij, G.H. and K. E. Wit (1996): Taking large undisturbed soil cores for use in monolith lysimeters, In preferential flow in water-repellent sandy soils - Model development and lysimeter experiments. Doctoral thesis, Wageningen Agricultural University, The Netherlands. 127-136
2) Inoue, M. (1994): Underground soil suction gauge, Sand Dune Research, 41 (2), 74-79 (in Japanese with English summary)
3) Inoue, M. and S. Shiozawa (1994): Measurement of electrical conductivity in soil columns by the four-electrode method and its application, Soil Physical Conditions and Plant Growth, Japan, 70, 23-28 (in Japanese with English summary)
4) Inoue, M. (1994): Simultaneous movement of salt and water in an unsaturated sand column, ALRC's Annual Report 1993-94, 13-26
5) Inoue, M. Y. Takeuchi and T. Yamamoto (1994): Effect of temperature variation on soil moisture measurement and improvement of moisture sensors in a sand dune field, Sand Dune Research, 41 (2), 49-55 (in Japanese with English summary)
6) Inoue, M., Y. Karatsu, K. Iimura, T. Yamamoto and S. Yamamoto (1996): Simultaneous measurement of solute and water transport during leaching process in sand under unsaturated condition, Sand Dune Research, 43 (1), 22-28 (in Japanese with English summary)
7) Inoue, M. (1996): Simultaneous measurement of solute and water transport in unsaturated soil, 35th Annual Conference in Society of Instrument and Control Engineers, 385-386 (in Japanese with English Summary)
8) Inoue, M. (1998): Evaluation of measuring precision of field-type dielectric soil moisture probes

using salty sand, Journal of Japan Society of Hydrology & Water Resources, 11(6), 555-564 (in Japanese with English summary)

9) Nakashima, M., M. Inoue, K. Sawada and C.Nicholl (1998): Measurement of the soil water content by Amplitude Domain Reflectometry Method and Its Calibration, Jour. of Japan Ground Water Society, 40(4), 509-519 (in Japanese with English summary)

10) Phene, C.J., D.A.Clark, G.E.Cardon and R.M.Mead (1992): Soil Matric Potential Sensor Research and Applications, in Avdances in Measurement of Soil Physical Properties: Bringing Theory into Practice, SSSA Special Publ. No.30 263-280