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NEW OPEN CHAMBER FOR MEASURING EVAPORATION

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A new equipment with an open chamber for measuring evaporation rate from the soil surface is described in this paper. The chamber differs from commonly used chambers due to the fact that it is completely open at the entrance. The chamber covers a ground area of 0.6 m^2 and has a volume of 0.3m^3. A suction arrangement has been used in passing air through the system and the ventilation rate can be regulated up to a maximum value of 90 m^3/h. The evaporation rate measured by the equipment showed good agreement with the evaporation rate measured by a balance both in the laboratory and the field. The net solar radiation was reduced by about 6% due to the chamber. The soil moisture under the chamber showed good agreement with the simulated values as well as with the soil moisture measured outside the chamber. The pressure difference within and outside the chamber was found to be negligible. The open chamber system minimizes its influence on the natural environment and thus gives better measurements.

Key Words: *open chamber, evaporation, accuracy check, soil moisture*

1. INTRODUCTION

Accurate estimates of evaporation have become increasingly important in various disciplines. For instance, in meteorology the water vapor cycle is of vital importance in understanding many physical processes in the atmosphere. In agricultural practice a minimum supply of water to crop can not be set without knowing how much water is evaporated. Soil physicists, hydrologists, meteorologists, agriculture and environmental engineers undertake research on evaporation because the phenomenon is interdisciplinary. Most of the research efforts concerning evaporation are aimed at searching for better ways to obtain accurate measurements of evaporation itself. Although there exist a vast number of experimental and theoretical methods for estimating evaporation such as lysimeter, energy budget/ Bowen ratio, correlation and TDR method, each method is blended with a set of defects and problems. For example, lysimeter method is time consuming and labor intensive and the temporal resolution of measurements often limited to one day[1)]. Moreover the application of this method to inhomogeneous area requires multiple instrumentation and is difficult to realize[2)].

Chambers have been used in measuring evaporation for several decades. The errors related to evaporation measurements in chambers are mainly due to alteration of natural profiles of radiation, turbulence, temperature and humidity[3)]. In most of the chamber designs these effects are controlled and minimized using devices such as deflectors, baffles, agitators, several types of meshes etc. Although these modifications give better results, there still remain problems with the unnatural environmental conditions created within the chambers and most of the designs are prone to be costly[4)].

For evaporation chambers with a `strong internal circulation`, the problem of absorption of water vapor on the Perspex walls exists up to some extent[2], while in the open chamber type this effect can be neglected.

It was our goal to develop an instrument that might give evaporation values in a more simple way. The device should be relatively inexpensive, easy to operate and transport and should measure evaporation accurately with minimal disturbance to the surrounding atmosphere.

The open chamber system described in this paper minimizes its influence on the natural environment and thus gives better measurements. In this equipment, the vapor flux is principally calculated from differences in measured absolute humidity between air entering and leaving an open-ended chamber and the flow rate through the chamber. This method is commonly used in measurements of gas exchange in plants[3), 4)]. Accuracy of the entire system was checked by comparing the measured evaporation with weight losses recorded by a balance both in the field and in the laboratory. The chamber-affected net radiation was compared with the unaffected. The soil moisture under the chamber was compared with the outside soil moisture distribution, under same conditions gravimetrically. Also, the moisture distribution was simulated by using a numerical model designed for the above problem.

2. EXPERIMENTAL APPARATUS

Figure 1 schematically illustrates the open chamber system used for measuring evaporation. The evaporation measuring equipment is based on the idea that when an air stream is injected to the chamber, the vapor flux from the surface into the chamber increases the absolute humidity of the extracted air. A suction arrangement is used in passing the air through the system to avoid pump effects[5),6)]. The system mainly consists of two sections; an open chamber and a set of equipment for measuring evaporation, proposed by Mohamed et al.[7)]. The interior dimensions of the Perspex chamber are; length 120 cm, width and height 50 cm each. For relatively easy handling and transportation, the chamber is made of two 60cm long sections which can be connected in the field. The bottom of the chamber is open. The uniqueness in this chamber is that it is open at its inlet. To sample the inflow air for the estimation of its average relative humidity and temperature, a small amount of air is sucked by a tube arrangement at the open end as shown in **Fig.1**. Tube inlets (44 numbers) are installed at the cross points of the wire net illustrated in **Fig.1**. A small pump is used in sucking air through the tubes provided at the entrance of the chamber. All tubes are connected to a small `box' type container, which is used to mix air for average measurements of inlet relative humidity and temperature. As shown in **Fig.1**, the sampling arrangement is spread throughout the cross section of the chamber, facilitating sampling of the entire air profile at the inlet. The inlet has the same cross sectional area as the entire box, which reduces the resistance to flow, while the system is under operation[8)]. A guide box has been used at the entrance of the chamber to facilitate the incoming air to be properly guided. The ceiling of the chamber has eight measuring holes to insert sensors to measure some useful parameters such as temperature, relative humidity, pressure and air velocity within the chamber at any level above the surface. These holes are kept closed at all times when the above measurements are not taken. All external pipes are insulated to avoid any air temperature changes while passing through the system.

During experiments with the new equipment, the measurements were taken in 20 seconds intervals and finally a 5 minutes average value was stored in the computer. The wind speed in the system can be regulated with the pump situated at the extreme end of the equipment. The flow rate was measured by a flow meter mounted on the pathway of the flow. A radiation meter is also mounted in the chamber, which is directly connected to the data logger. Inlet and outlet temperature, humidity, flow rate and radiation values were directly recorded with the data logger.

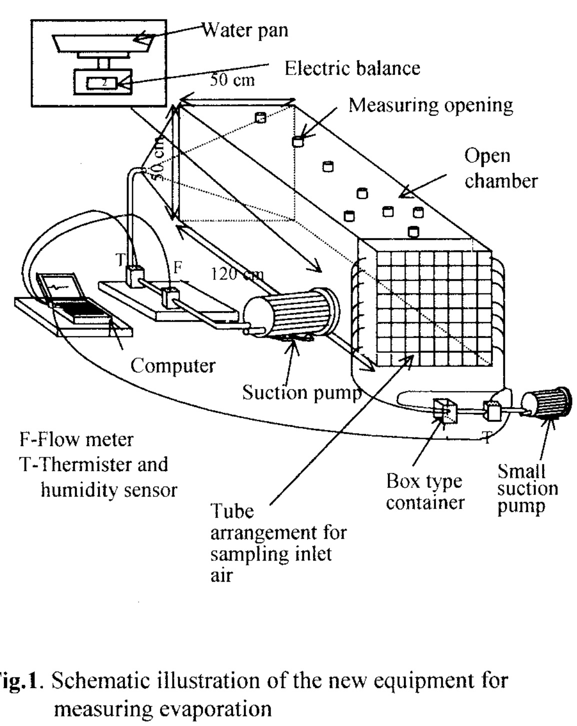

Fig.1. Schematic illustration of the new equipment for measuring evaporation

3. EVAPORATION MEASURING TECHNIQUE

The water vapor flux (E) from the soil surface can be calculated as a product of the rate of flow of air through the chamber and the difference between inlet and outlet absolute humidity values, divided by the area covered by the box and the density of the water. The absolute humidity of the inlet and outlet air can be calculated using the temperature and relative humidity measured at the inlet and outlet respectively. The method of calculation of absolute humidity at the inlet and outlet is well explained in Mohamed et al.[6].

The vapor flux can now be calculated as:

$$E = -86.4(10^3)\frac{Q(\beta_{out} - \beta_{in})}{\rho A} \quad (1)$$

where E is the evaporation rate (mm/day), Q is the volumetric flow rate of the air (l/s), β_{out} and β_{in} are the absolute humidity (Mg/m^3) of the air after and before passing through the chamber respectively, ρ is the density of the water (Mg/m^3), and A is the area covered by the chamber (m^2).

4. CHECKING THE ACCURACY OF THE NEW OPEN CHAMBER

(1) Accuracy check in the laboratory

Accuracy of the entire chamber system was checked in the laboratory. A water pan was placed on an electric balance and subsequently the unit was placed under the chamber as illustrated in **Fig.1**. The weight losses of the water pan were recorded by the balance and were calculated from the evaporation rate measured by the equipment as well, during the period from 0:0 hrs. to 17:00 hrs. on 18, June 2000. The operating wind speed of the chamber during the period of the experiment was controlled to be $0.05 ms^{-1}$. The relative humidity and temperature were in the range of 65-75% and 24-27℃ respectively.

(2) Accuracy check in the field

To investigate the accuracy of the open chamber system under field conditions, the water losses from an exposed water pan under the chamber were recorded by the balance, and again compared with the values calculated from the rate measured by the equipment. The field experiment was carried out in the premises of Saitama University from 9:00 hrs. on 21, June 2000 to 12:00 hrs. on 22, June 2000. Halfway of the experiment a small rainfall was recorded from 21:20 hrs. on 21, June 2000 to 2:00 hrs. on 22, June 2000.

(3) Net Radiation

The chamber affected net radiation was compared with the unaffected area just outside the Perspex chamber by two calibrated net radiometers used simultaneously.

(4) Soil moisture

To understand the variations of soil moisture distribution inside and outside the chamber two artificial wooden plots of size (LxWxH) 1.2 x 0.5 x 0.3 m were created in the laboratory and subsequently filled with a fine sand (Toyoura sand). The used sand had a mean grain diameter of 0.19 mm, a saturated hydraulic conductivity of 0.02 cm/s, a particle density of 2.63 Mg/m^3, a dry bulk density of 1.50 Mg/m^3, and a porosity of 0.445. First both plots were completely saturated and drainage was allowed for a period of 24 hours. Two tensiometers were installed at the extreme bottom of each plot. The chamber was placed on top of one experimental plot and measurements were started for a continuous dry down period of 16 days. The operating wind speed of the chamber system was controlled to a value of $0.05 ms^{-1}$. The plot outside the chamber was also subjected to same conditions that existed in the plot under the chamber. Soil moisture in each plot was obtained gravimetrically and estimated by numerical simulation.

a) Theory behind the numerical simulation in estimating soil moisture

The governing flow equation for one-dimensional isothermal Darcian flow in an unsaturated porous medium is given by the following form of Richards equation:

$$C\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial h}{\partial z} + K\right) \quad (2)$$

where C is the specific water capacity (m^{-1}), K is the hydraulic conductivity (m/s), h is the soil-water pressure head (m), t is the time (s), and z is the vertical coordinate (m) positive upward. Equation (2) can be solved numerically if the initial and boundary conditions of the flow and the properties of the soil are defined. Initial and boundary conditions applicable to the evaporation experiments carried in this study are as follows:

$$h(z,0) = h_i(z) \quad (3)$$

$$-K\left(\frac{\partial h}{\partial z}+1\right)\Bigg|_{z=L} = q_{evap}(t) \quad (4)$$

$$q(0,t) = -K\left(\frac{\partial h}{\partial z}+1\right) = 0 \quad (5)$$

where h_i is the initial soil-water pressure head (m), $q_{evap}(t)$ is the time-variable evaporation rate imposed at the soil surface (m/s), which is measured by the open chamber system and L is a coordinate of the soil surface (m).

Equation (2), subjected to the above initial and boundary conditions, was solved numerically by a one-dimensional finite-element code with Galerkin technique, developed for the above problem.

b) Parameter estimation

The soil water retention curve was assumed to be of the same form described by Van Genuchten[9]:

$$\theta_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (0 \le \theta_e \le 1) \quad (6)$$

$$\theta_e = \left(1 + |\alpha h|^n\right)^{-m} \qquad (\alpha > 0) \quad (7)$$

$$n = \frac{1}{1-m} \qquad (0 < m < 1, n > 1) \quad (8)$$

$$K = K_s \theta_e^{1/2}\left(1 - (1 - \theta_e^{1/m})^m\right)^2 \quad (9)$$

$$C = \alpha(n-1)(\theta_s - \theta_r)\theta_e^{1/m}(1 - \theta_e^{1/m})^m \quad (10)$$

where θ is the water content per bulk volume (m^3/m^3), θ_e is the effective water content, θ_r and θ_s denote the residual and saturated volumetric water content (m^3/m^3) respectively, K_s is the saturated hydraulic conductivity (m/s), and α (m^{-1}), n and m are empirical parameters. The Van Genuchten parameters for Toyoura sand were obtained by a laboratory test following Mohamed et al.[6] and the values are as follows; $\theta_s = 0.995$ m^3/m^3, $\theta_r = 0.01$ m^3/m^3, m = 0.89654, $\alpha = 0.02642$ cm^{-1}.

5. RESULTS

Figure 2 illustrates the results of the accuracy check carried out in the laboratory for a period of 16 hours. **Figure 2(a)** and **(b)** show the time variations of temperature and humidity measured at the inlet and outlet of the chamber, respectively. The evaporation rates measured by the equipment and the balance are given in **Fig. 2(c)**. The unstable evaporation rate visible in the data might have occurred due to the fact that the measurements were taken in 20 seconds intervals and finally a 5 minutes average value was obtained. It is visible from both **Fig. 2(a)** and **(b)** that the temperature and humidity in atmosphere are rapidly changing.

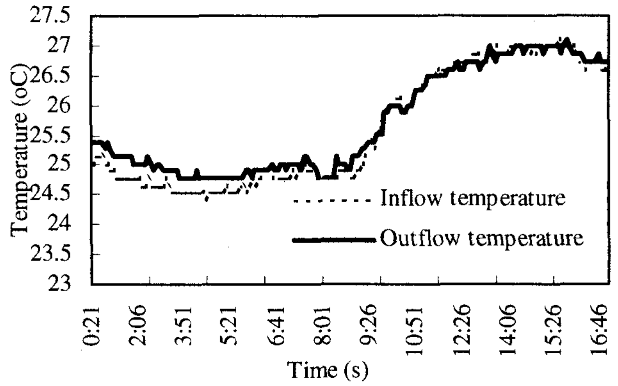

Fig.2(a). Transient change of temperature of inflow and outflow during the laboratory check

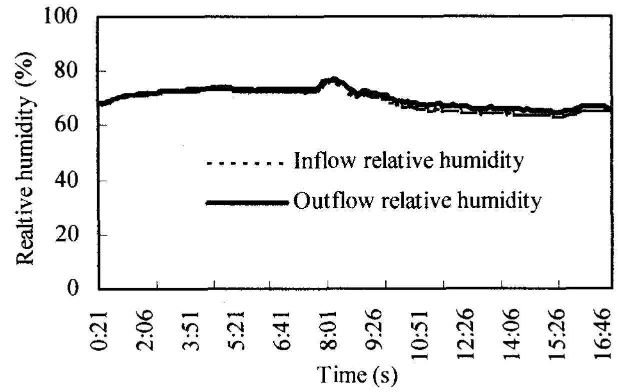

Fig.2(b). Transient change of relative humidity of inflow and outflow during laboratory check

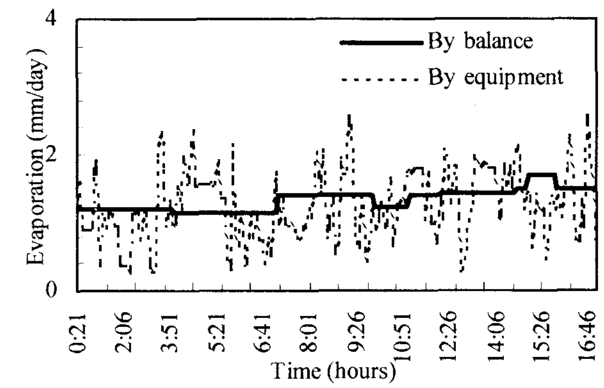

Fig.2(c). Transient change of evaporation rate by the balance and the equipment during the laboratory check

Also there is a possibility that when air is sampled for relative humidity and temperature at the inlet, the 'same' air is not sampled at the outlet. The sampled inlet air goes via the tube arrangement to the mixing box and finally to the measuring point while rest of the air goes through the chamber and the external pipes to the outlet measuring point. If the sampled air reaching the inlet measuring point is slower or faster than the same air reaching the outlet measuring point, a 'time difference' is said to occur. This 'time difference' might be one of the reasons for the data to be scattered.

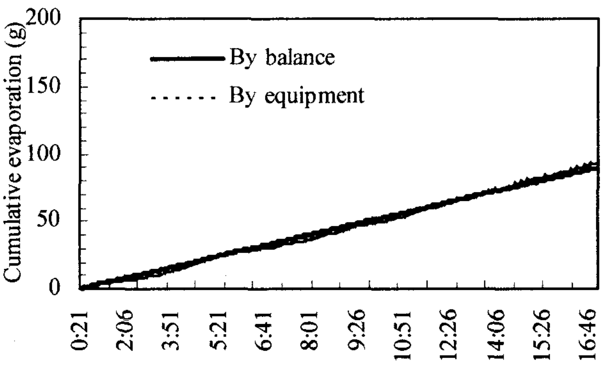

Fig.2(d). Cumulative values of evaporation by the balance and the equipment in the laboratory

Figure 2(d) compares the cumulative evaporation rate measured by the equipment and the balance. It can be seen that the difference between the two methods is small and found to be 3%. This shows that even the data are scattered the average evaporation gives results of better accuracy.

Figure 3 illustrates the results of the accuracy check carried out in the field for a period of 26 hours. The temperature and humidity variations during the field check are shown in **Fig. 3(a)** and **3(b)** respectively. The evaporation rate, from a water pan measured by the chamber and calculated from the weight losses by a balance are compared in **Fig. 3(c)**. As a small rainfall was recorded during the experiment, the results can be divided into two parts, before and after rain. It is visible that the evaporation data is scattered, which might have occurred due to the same reasons stated in the laboratory test.

Fig. 3(d) compares the cumulative values of evaporation between the balance and the chamber. Approximately 11 hour measuring period before rain showed an average difference of 5 % between the two methods. The cumulative evaporation obtained by the balance and the equipment showed an average difference of 10.5%, during the period following the rainfall. The high value of error after rainfall might have occurred due to the instantaneous variations in the atmosphere, which is usual after a rainfall. Even so the accuracy is still

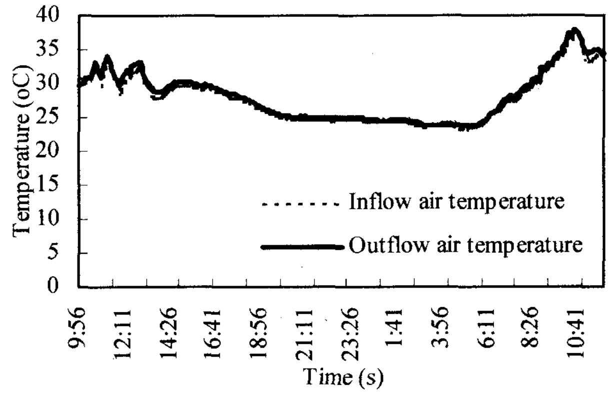

Fig.3(a). Transient change of temperature of inflow and outflow air during the field check

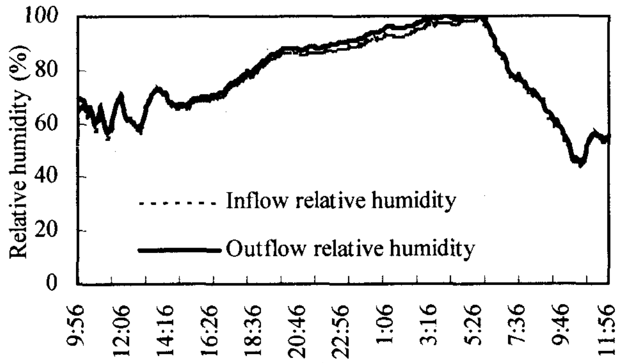

Fig.3(b). Transient change of relative humidity of inflow and outflow air during the field check

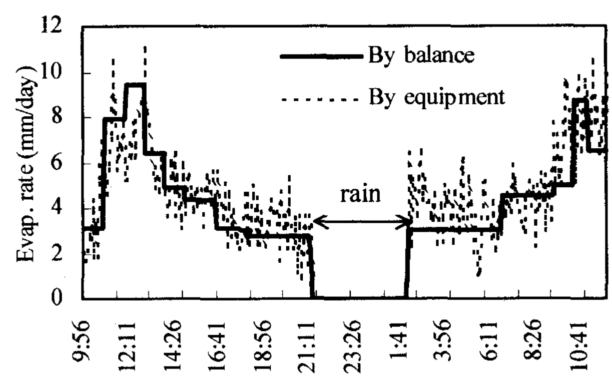

Fig.3(c). Transient change of evaporation rate by the balance and the equipment during the field check

high enough to rely on the new chamber technique under field conditions.

The chamber affected net radiation was compared with the unaffected value and the difference was found to be approximately -6%. This might have slightly reduced the evaporation value measured by the equipment during daytime. The pressure inside the chamber relative to the ambient atmospheric pressure was found to be very small and was impossible to measure due to the unavailability of a pressure meter of high accuracy. It is clear from **Fig.4** that the soil moisture under the chamber

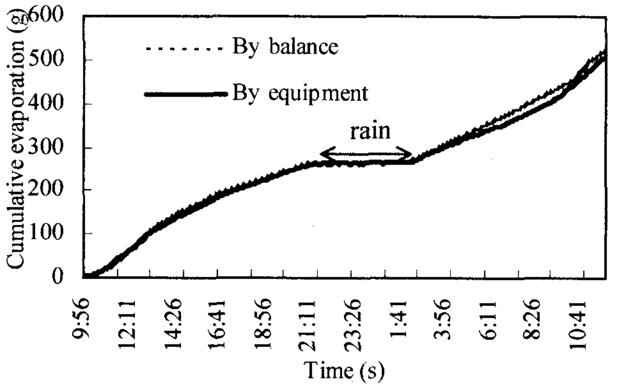

Fig.3(d). Cumulative values of evaporation by the balance and the equipment during the field check

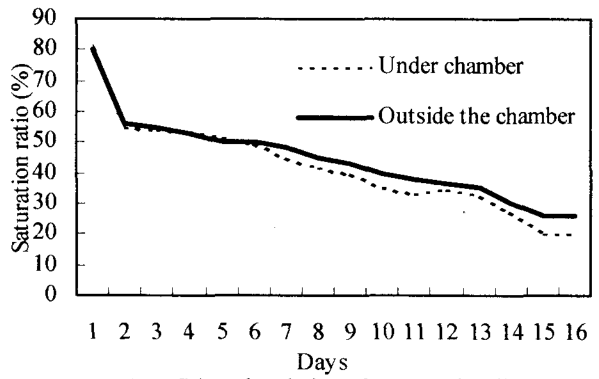

Fig.4. Diurnal variation of measured soil moisture under and outside chamber

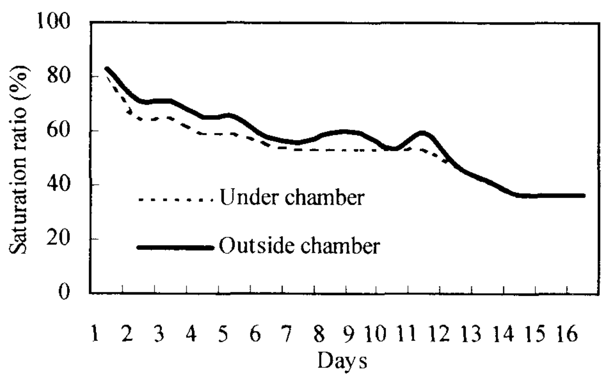

Fig.5. Diurnal variation of simulated soil moisture under and outside the chamber

shows good agreement with the 'chamber unaffected' values when obtained gravimetrically. The simulated saturation ratio, under and outside the chamber are given in **Fig.5**. The difference between the chamber affected and unaffected soil moisture was found to be small, both experimentally as well as numerically. So, it is possible to conclude the affect of chamber on soil moisture is small.

6. CONCLUSIONS

We were successful in building a simple evaporation measuring equipment which is relatively inexpensive, easy to operate, transport and gives satisfactory estimates of evaporation rate. The results obtained by accuracy checks both in the laboratory and in the field indicate the suitability of the equipment in measuring evaporation under different conditions. As the chamber is completely open at the inlet, the disturbance to the surrounding atmosphere is minimized, thus meeting the demand of 'not disturbing the natural environment' is satisfied. The major difference between condition inside the chamber and surrounding atmosphere is that the equipment has a constant ventilation rate while the atmospheric wind velocity is difficult to understand. This difference is some times useful in checking how sensitive a given soil surface is to wind speed.

The net radiation was reduced by about 6% when measured within the chamber, which might have decreased the evaporation measured by the equipment. The chamber 'affected' soil moisture shows a satisfactory agreement with the simulated values as well as with the 'unaffected' soil moisture distribution which lead us to believe that the chamber has little effect on soil moisture distribution. The pressure within the chamber was compared roughly with the ambient atmosphere and the difference was found to be negligible.

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