EVAPOTRANSPIRATION CALCULATION AND DETERMINATION OF EVAPORATION EFFECT IN THE SOIL USING STABLE ISOTOPES (^{18}O AND ^{2}H) AND HYDROMETRIC MEASUREMENTS

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ABSTRAK

Perhitungan evapotranspirasi sangat dibutuhkan dalam perencanaan hidrologi, agronomi, kehutanan, sumber daya air, irigasi, pemodelan ekosistem, dan lain sebagainya. Evapotranspirasi dapat dihitung dengan berbagai macam metode, namun perhitungan langsung dari aktual evapotranspirasi sangat jarang ditemui dan mahal. Neraca air dan pemodelan numerik HYDRUS-1D digunakan untuk menghitung aktual evapotranspirasi dengan metode Penman-Monteith sebagai pembanding. Perhitungan dilakukan pada sebuah lisimeter dengan rumput sebagai tanaman. Hasil dari perhitungan menunjukkan bahwa Penman-Monteith dan model HYDRUS-1D mempunyai pola yang sama, sementara hasil dari perhitungan neraca air sangat dipengaruhi oleh perubahan tampungan air di dalam tanah. Evapotranspirasi rata-rata dari neraca air, Penman-Monteith dan HYDRUS-1D secara berurutan adalah 3,4 mm/hari, 3,6 mm/hari dan 4,2 mm/hari. Kedalaman dari efek evapotranspirasi adalah 20 cm yang dapat dideteksi dengan menggunakan pengukuran isotop ^{2}H dan ^{18}O.

***Katakunci**: Evapotranspirasi, neraca air, Penman-Monteith, HYDRUS-1D, dan isotope*

ABSTRACT

Evapotranspiration estimation is needed in a wide range of problems in hydrology, agronomy, forestry, water resources planning, irrigation engineering, ecosystem modelling, etc. Evapotranspiration can be computed using many methods. However,direct measurements of actual evaporation are rarely available and expensive. Water balance and HYDRUS-1D numerical modelling have been used to calculate actual evaporation by Penman-Monteith method for comparison in a grassland lysimeter. Results show that the Penman-Monteith and HYDRUS-1D model have the same pattern while fluctuative evapotranspiration from water balance model is strongly influenced by storage changes in the soil. The average of evapotranspiration is 3.4 mm/d, 3.6 mm/d and 4.2 mm/d calculated using water balance, Penman-Monteith and HYDRUS-1D models respectively. Moreover, effect of evapotranspiration in the soil of 20 cm is detected by using the stable isotopes (^{2}H and ^{18}O) technique.

***Keyword**: Evapotranspiration, water balance, Penman-Monteith, HYDRUS-1D, stable isotopes*

INTRODUCTION

Evapotranspiration estimation is needed in a wide range problems in hydrology, agronomy, forestry, water resources planning, irrigation engineer, ecosystem modelling, etc (Xu and Singh, 2005). Evapotranspiration is a combination of soil evaporation, transpiration by plants, evaporation from open water surfaces, and water intercepted by vegetation. Soil evaporation and plant transpiration are generally combined as one single term which is evapotranspiration without taking into account the interception and usually interception has been neglected in many hydrology analysis. However, interception flux in some cases is an important component in the evaporation process and should not be neglected (Savenije, 2004; Gerrits, et al., 2007). Hence, in this paper, I described evapotranspiration as a combination of soil evaporation, transpiration and interception.

Evapotranspiration can be computed using many methods such as water budget, mass-transfer, Penman-Monteith (1965), Priestley and Taylor (1972), Thornthwaite (1948), Blaney and Criddle (1950) and Makking (1957) (Gong, *et al*., 2006). In contrast, direct measurements of actual evapotranspiration are rarely available and expensive thus it is estimated using Penman-Monteith or pan evaporation and empirically derived correction factors and pan coefficient respectively (Sumner and Jacobs, 2005). Penman-Monteith method is recommended by FAO to calculate evapotranspiration if the data are available. The difficultly using this method is that this method requires data on aerodynamic resistance and surface resistance which are not readily available, thus the Penman-Monteith method has been limited in practical use (Xu and Singh, 2005).

This study is using two methods to calculate the actual evapotranspiration, which are water balance method in the lysimeter and HYDRUS-1D numerical modelling. Penmann-Monteith method has been used for comparison. Water balance method can be used to calculate the actual evaporation by measuring the other components of water fluxes in the soil (precipitation, runoff, percolation, and storage changing) (Allen, *et al*., 1998). HYDRUS-1D model can be used to simulate the water and solute movement in unsaturated, partly saturated or fully saturated porous media (Simunek, et al., 2008). HYDRUS-1D model is used for not only simulating the water movement in the soil but also calculating the actual evapotranspiration by activated root water uptake component in the model. In addition, interception value is taking into account in the model.

The objectives of this study are to calculate the actual evapotranspiration using water balance and numerical modeling. In addition, Potential evapotranspiration has been calculated using Penman-Monteith method for comparison. Moreover, the effect of evaporation in the soil has been determined using stable isotopes deuterium (^{2}H) and oxygen-18 (^{18}O) as a tracer. The reasons using these isotopes as tracers are: chemically and biologically stable, there is no isotopic fractionation in these tracers during water uptake by roots (Ehleringer and Dawson, 1992, Kendall and McDonnell, 1998, Tang and Feng, 2001, Williams, *et al*., 2004, Wenninger, *et al*., 2010, Koeniger, *et al*., 2010), and when the water is transported between roots and leaves, the isotopic composition is remaining the same not changing until it reaches the leaves (Ehleringer and Dawson, 1992; Gat, 2010; Kendall and McDonnell, 1998; Riley,*et al*., 2002; Tang and Feng, 2001; Williams, *et al*., 2004).

MATERIAL AND METHODS

1 Lysimeter Set-up

There are numerous measuring devices used in this study. All measurement devices are connected to data logger system. A grassland lysimeter experiment was located in UNESCO-IHE laboratory using a weighing lysimeter made from a PVC pipe as the main device with five soil moisture sensors (5TE ECH2O probes with acuracy 0.08% for soil moisture sensor, 0.05 dS/m for EC sensor and 0.1 °C for temperature sensor) and five rhizon samplers attached into it (see Figure 1). The lysimeter has a depth of 40 cm and a diameter of 20 cm. The interval between two sensors is 6.67 cm. Rhizon samplers are installed in the opposite direction of soil moisture sensors. This is to prevent rapid soil moisture changing due to abstraction of water from rhizon samplers. One EM50 data logger is used to record the soil moisture data at one minute intervals. The bottom of the lysimeter is filled up with drainage material to let the percolation comes out to the percolation meter made by Decagon with accuracy 0.1 mm. Another data logger is used to record the percolation water into the wick passive flux device at one minute intervals. Soil water in every layer is taken from the lysimeter using rhizon samplers applying a vacuum with 30 ml syringes. Soil properties such as residual water content, saturated water content, parameter alpha and n, saturated hydraulic conductivity, and tortuosity parameter were measured using HYDRUS-1D inverse modelling. Only grain size analysis was determined in the laboratory in three layers (top, middle and bottom). Actual evapotranspiration was measured by the change of weight recorded with a Kern DE60K20N platform balance every minute. Rainfall applied in the lab based on average pattern of summer conditions (June to July) recorded in Rotterdam from 2005 to 2010.

2 Meteorological Measurements

A weather station (Catec Clima Sensor 2000 type 4.9010.00.061) using a Squirrel View data logger was installed in the laboratory to measure relative humidity, temperature, wind speed, and solar radiation. The accuracy of climate equipments is 10% for pyranometer, <0.5 m/s for wind speed, 0.15 °C for temperature and 3% for relative humidity. One lamp (OSRAM powerstar 400 W) is installed above the lysimeter to compensate the sunlight inside the laboratory. Timers have been used to setting the lamp and fan. The lamp setting is switch on at 6 AM in the morning and switch off at 6 PM and adjusted several times. The fan is turned on at 6 AM and

turned off at 5 PM. The radiation, wind speed, temperature and humidity measured in the UNESCO-IHE laboratory are in between 1-31 W/m^2, 0-1.2 m/s, 18-29 °C and 18-45% respectively.

Laboratory climate conditions have been re-constructed to represent the spring to summer conditions as in the field because spring and summer conditions are the most important season for plant to grow. The average data from Rotterdam station has been used for comparison from year 2005 until 2010 (see Table 1). Evapotranspiration in Rotterdam is between 1.1-2.8 mm/d for spring and 2.5-3.5 mm/d for summer conditions.

3 Isotopes Analysis

Water samples from the field were isotopically analyzed using LGR liquid water isotope analyzer (LWIA-24d). The analyzer measures ^{18}O and ^{2}H in liquid water samples with high accuracy (±0.2‰ and ±0.6‰, respectively) in a sample volume of <10µl. Data screening was done two times for isotopes analysis. First screening has been done using LGR software to check the analysis results and parameters, and second screening has been done in a spreadsheet to obtain good results. In general, water samples are taken twice a week but in the middle of the experiment, the water samples are taken in a higher temporal resolution; everyday for a week. The experiments start from November 10, 2010 until January 31, 2011.

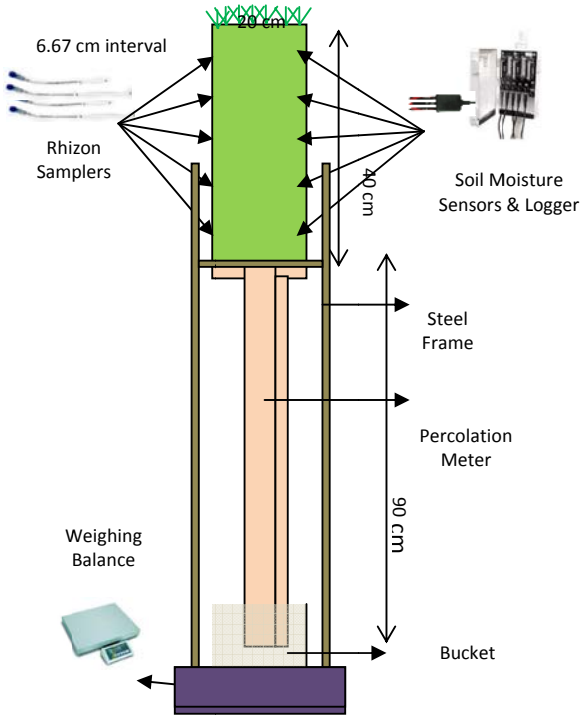

Figure 1 Lysimeter setup at UNESCO-IHE laboratory

Table 1 Climate data from Rotterdam station

Month	Sunshine (hour)	Temperature (celcius)	Wind Speed (m/s)	Incoming Short Wave (W/m^2)	Ep Makkink (mm/d)
Jan	2.5	3.9	5.6	29.8	0.3
Feb	2.6	3.8	4.6	46.9	0.5
March	4.5	6.3	5.1	100.7	1.1
Apr	7.2	10.2	3.9	180.8	2.3
May	7.1	13.3	4.2	204.4	2.8
Jun	**7.9**	**16.3**	**3.5**	**234.6**	**3.5**
Jul	**7.4**	**18.8**	**3.9**	**214.2**	**3.3**
Aug	**6.0**	**17.3**	**3.9**	**169.7**	**2.5**
Sep	5.2	15.3	3.7	123.5	1.8
Oct	3.9	12.0	4.1	73.1	1.0
Nov	2.5	8.4	5.2	32.6	0.4
Dec	1.9	4.2	4.8	21.7	0.2

The common standard for isotopes is the Vienna Standard Mean Ocean Water (VSMOW) which has been defined by International Atomic Energy Agency (IAEA) in Vienna. Isotopic abundance for oxygen and hydrogen based on VSMOW standard is described as a follow:

$$R_{18_O/16_O} = \left(\frac{^{18}O}{^{16}O}\right)_{VSMOW} = 2005.2 \pm 0.45 * 10^{-6} \quad (1)$$

$$R_{D/H} = \left(\frac{^{2}H}{^{1}H}\right)_{VSMOW} = 155.76 \pm 0.05 * 10^{-6} \quad (2)$$

The isotopic abundance ratio of sample (R_{sample}) is given with the isotopic abundance ratio standard:

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \quad (3)$$

In hydrology it is convenient and common to multiply the $\delta^{18}O$ and $\delta^{2}H$ values by 1000 as ‰ difference from the standard being used. Positive values indicate an enrichment of isotopes values compared to the standard. On the other hand, negative values indicate a depletion of heavier isotopes in the sample.

4 Evapotranspiration Calculation

Penman-Monteith Method

Evapotranspiration has been calculated using Penman-Monteith method and water balance. Penman-Monteith method is the most accurate method to calculate potential evapotranspiration as recommended by FAO (Food and Agriculture Organization). Formula to calculate Penman-Monteith evapotranspiration is described below:

$$Ep = \frac{C}{L}\left(\frac{sR_N + c_p\rho_a(e_s - e_d)/r_a}{s + \gamma(1 + r_c/r_a)}\right) \quad (4)$$

Where:

E_p , potential evapotranspiration of grass [mm d^{-1}]

C , constant to convert units from kg m^{-2} s^{-1} to mm/day (86400)

R_N , net Radiation at the Earth's surface [W m^{-2}]

L , latent heat of vaporization (L = 2.45*10^6 J kg^{-1})

S , slope of the Temperature –Saturation vapour pressure curve [kPa K^{-1}]

c_p , specific heat of air at constant pressure (c_p = 1004.6 J kg^{-1} K^{-1})

ρ_a , density of air (1.2047 kg m^{-3} at sea level)

e_d , actual or dew point vapour pressure of the air at 2 m height [kPa]

e_s , saturation vapour pressure for the air temperature at 2 m height [kPa]

γ , psychometric constant (γ = 0.067 kPa K^{-1} at sea level)

r_a , aerodynamic resistance [s m^{-1}]

r_c , crop resistance, (r_c = 70 s m^{-1} for grass, FAO)

Actual or dew point vapour pressure (e_d) and saturation vapour pressure (e_s) can be calculated using formula below:

$$e_s = 0.6108e^{\frac{17.27Ta}{Ta+237.3}} \quad \text{[kPa]} \quad (5)$$

$$e_d = \frac{RH * e_s}{100} \quad \text{[kPa]} \quad (6)$$

Where:

T_a , 24 hour mean temperature of the air (°C)

RH , relative humidity (%)

The slope of the saturation vapour pressure-temperature curve $s = de_s/dTa$ is described below:

$$s = \frac{4089e_s}{(237.3 + T_a)^2} \quad \text{[kPa K}^{-1}\text{]} \quad (7)$$

r_a is aerodynamic resistant which is a function of the wind speed (U). The simplified formula to calculate $r_a$is as a follow:

$$r_a = \frac{208}{U} \quad \text{[s m}^{-1}\text{]} \quad (8)$$

r_a in formula 5 is only valid for 2 m measurement heights. For the other measurement heights, the r_a formula is described as a follow:

$$r_a = \frac{ln\left[\frac{z_m - d}{z_{om}}\right] ln\left[\frac{z_h - d}{z_{oh}}\right]}{k^2 U_z} \quad \text{[s m}^{-1}\text{]} \quad (9)$$

Where:

z_m , height of wind measurements (m)

z_h , height of humidity measurements (m)

d , zero plane displacement height = 2/3 crop height (m)

z_{om} , roughness length governing momentum transfer = 0.123 crop height (m)

z_{oh} , roughness length governing transfer of heat and vapour = 0.1 z_{om} (m)

k ,von Karman's constant, 0.41 (-)

U_z , wind speed at height z (m s^{-1})

Net long wave radiation (R_{nL}) emitted by the earth's surface, water vapour and droplets may be estimated using this following formula:

$$R_{nL} = \sigma(273 + T_a)^4\left(0.34 - 0.139\sqrt{e_d}\right)\left(0.1 + 0.9\frac{n}{N}\right) \quad \text{[W m}^{-2}\text{]} \quad (10)$$

σ is the Stefan-Boltzmann constant (σ = 5.6745*10^{-8} w m^{-2} K^{-4}).

Short wave radiation (R_{nS}) can be calculated using formula:

$$R_{nS} = (1 - r)*R_N \quad \text{[W m}^{-2}\text{]} \quad (11)$$

Net radiation (R_N) is the total net long wave radiation and net short wave radiation. r is albedo or reflection coefficients. r value for grass is between 0.22-0.25.

Evapotranspiration calculated using Penman-Monteith formula is known as potential evapotranspiration. Therefore, actual evapotranspiration is calculated using weighing lysimeter and water balance method.

Water Balance Method

The water balance is used to calculate the actual evapotranspiration as an unknown variable. This study uses surface water balance analysis in the vadose zone which is based on continuity equation:

$$I - O = \frac{\mathrm{d}S}{\mathrm{d}t} \quad (12)$$

Input parameter for this research is precipitation and output parameters are runoff, actual evapotranspiration and percolation. This complete water balance is illustrated in equation 13.

$$P - R - E_a - P_e = \frac{\mathrm{d}S}{\mathrm{d}t} \quad (13)$$

Where:

P , precipitation [LT^{-1}]

R , runoff [LT^{-1}]

E_a , evapotranspiration [LT^{-1}]

P_e , percolation [LT^{-1}]

$\mathrm{d}S/\mathrm{d}t$, changes of storage in the soil [LT^{-1}]

Runoff variable is neglected in this research because there is no runoff in the lysimeter in the laboratory.

HYDRUS-1D Model

The boundary conditions used for this study are atmospheric condition for the upper boundary and free drainage for the bottom boundary. In addition, interception is included in HYDRUS-1D simulations. Soil parameters were obtained from HYDRUS-1D by inverse modeling. The root water uptake subroutine has been performed to simulate the amount of water taken up from the soil for transpiration using the default parameters for grass. Inverse modeling has been performed for parameter calibration and result comparison using the van Genuchten-Mualem method. The calibration for HYDRUS-1D has been carried out using December data while validation has been executed after calibration process using the calibrated parameters for month January with hourly time step.

The HYDRUS-1D model for one-dimensional water movement is based on the modified Richards equation with the assumption that the air phase plays an unimportant role in the liquid flow process and water flow due to thermal gradient can be neglected.

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[K\left(\frac{\partial h}{\partial z} + 1\right)\right] - S \quad (14)$$

Where:

θ , volumetric soil water content [L^3/L^{-3}]

t , time [T]

h , soil water pressure head [L]

z ,gravitational head and vertical coordinate [L]

K , unsaturated hydraulic conductivity [LT^{-1}]

α , angle between the flow direction and vertical axis (α=0 for vertical flow, α=90 for horizontal flow)

S , sink term, defined as the volume of water removed from the soil per unit of time due to plant water uptake [L^{3}L^{-3}T^{-1}]

The sink term (S) is defined as:

$$S(h) = \alpha(h)S_p \quad (15)$$

Where S_p is the potential water uptake rate [T^{-1}] and α(h) is given dimensionless function of the soil water pressure head ($0 \le \alpha \le 1$). The term α(h) was defined as functional form by Feddes et al. (1976).

$$\alpha(h) = \begin{cases} \frac{h-h_4}{h_3-h_4}, & h_4<h\le h \\ 1, & h_3<h\le h_2 \\ \frac{h-h_1}{h_2-h_1}, & h_2<h\le h_1 \\ 0, & h\le h_4 or h\ge h_1 \end{cases} \quad (16)$$

Where h, h_1, h_2, h_3 and h_4 are threshold parameters. Crop specific values for these threshold parameters are available in the HYDRUS database.

RESULTS AND DISCUSSION

Hydrometric Measurements

The hydrometric measurements in the laboratory consist of climate parameter, soil moisture, temperature, EC and percolation measurements. The average values of pyranometer, windspeed, temperature, and humidity are 10.5 W/m^2, 0.7 m/s, 23.9 °C and 32.2% respectively for November, 13.2 W/m^2, 0.7 m/s, 23.6 °C and 24.8% for December and 8.9 W/m^2, 0.6 m/s, 25.9 °C and 28.8% for January. In comparison, the laboratory data have less windspeed and radiation compared with field data from Rotterdam. In contrast, laboratory data have dryer humidity and higher temperature compared with Rotterdam data. Potential evapotranspiration calculation using Penman-Monteith in the laboratory used measurement heights 20 cm. Thus, the formula used in the calculation is not the simplified formula but the original formula

(number 9). The results for the potential evapotranspiration calculated using Penman-Monteith method is shown in Figure 2.

Figure 2 shows the potential evapotranspiration at UNESCO-IHE laboratory with several stages. The first stage around 3.3 mm/d start from 16 until 18 November 2010 are the values with first setting before an additional lamp was installed and the fan speed was increased. The second stage is the highest setting for climate setting in the lab. The highest setting is installed at 19 November 2010; this is the reason why the value for 19 November is in between first and second stages. The highest value for evapotranspiration in the laboratory is around 4.5 mm/d. This is the maximum value can be achieved in the laboratory calculated using Penman-Monteith. The fourth stage was starting from 19 November 2010 until the end of measurements. The higher fluctuation was caused by the climate adjustment during the measurements. The average of potential evapotranspiration during measurements period is 3.6 mm/d, which can represent the summer condition as in the field.

Five soil moisture sensors are placed inside the lysimeter using the same interval (6.67 cm). Port 1 is located in the upper part (6.67 cm from surface) followed by port 2 (13.3 cm from surface), port 3 (20 cm from surface), port 4 (26.7 cm), and port 5 in the bottom (33.3 cm from surface). Same locations were used for Rhizon samplers also, however, the locations for Rhizon samplers are on the opposite direction with soil moisture sensors.

The fluctuation of soil moisture strongly depends on precipitation water (see Figure 3). The range of soil moisture in the lab is in between 0.22-0.47 VWC (m^3/m^3). The sensors affected the most by precipitation water are port 1, port 2 and port 4. Port 1 and port 2 are predictable to have quick response to the precipitation water, but port 4 shows surprisingly response. In contrast, port 5 as the bottom port has less response to the precipitation water. This fast response in port 2 and 4 can be caused by macropores in the soil, soil cracking, or flow at the boundary between soil monolith column and the PVC pipe.

There is little water percolating to the drain gauge. The maximum percolation is 0.3 mm/d and the total percolation during the measurement period is 2.4 mm (see Figure 4-left). The results from the weighing balance are used to calculate the change in storage inside the lysimeter. The storage changing is strongly influenced by precipitation and not by percolation since the percolation water is little. Hence, the mass loss per day is around 0.08-0.1 kg/d without precipitation water; therefore, actual evapotranspiration is 0.08-0.1 kg/d or ± 3.18 mm/day. Figure 4-right shows the changing storage and precipitation in the laboratory.

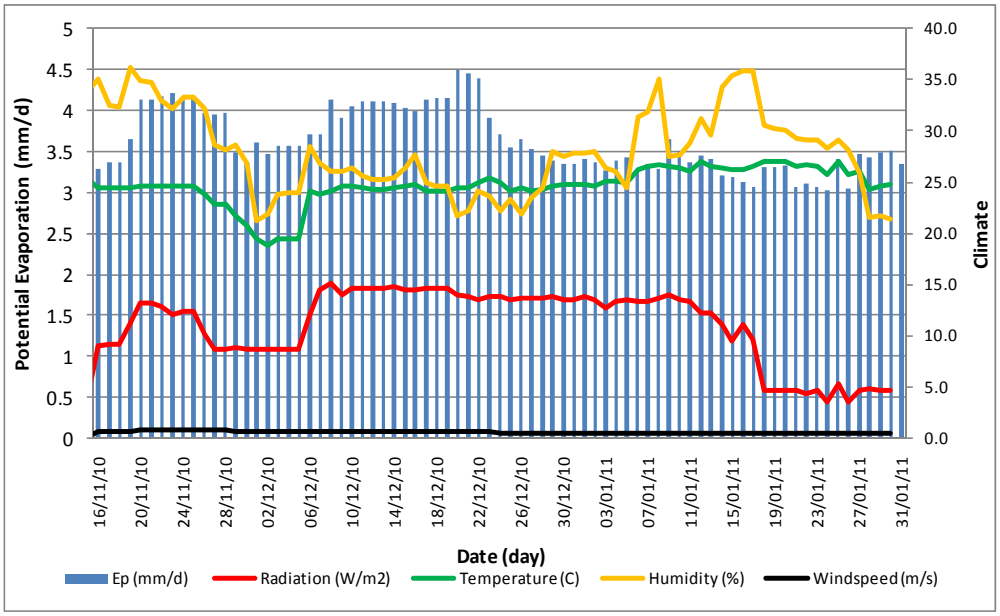

Figure 2 Potential evapotranspiration at UNESCO-IHE Laboratory

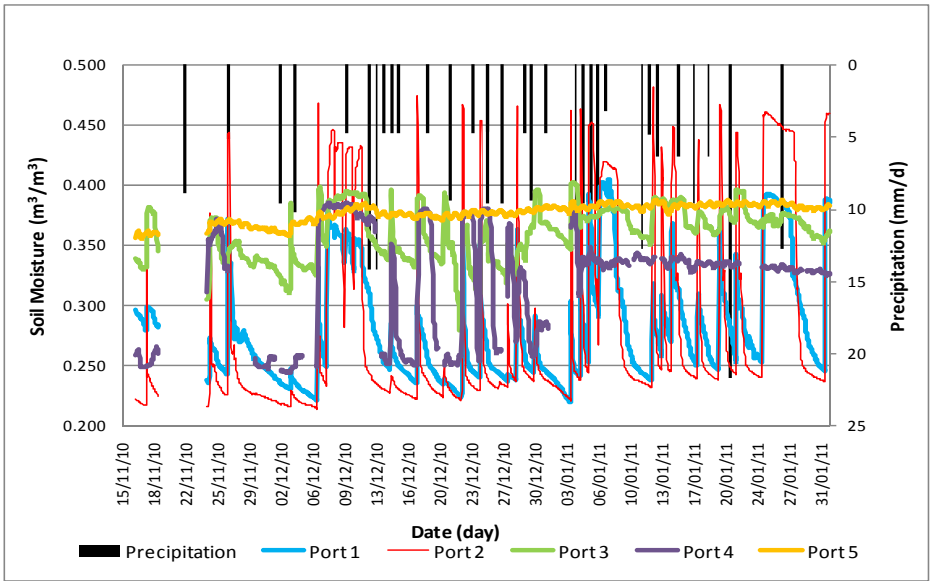

Figure 3 Soil moisture measured at UNESCO-IHE laboratory

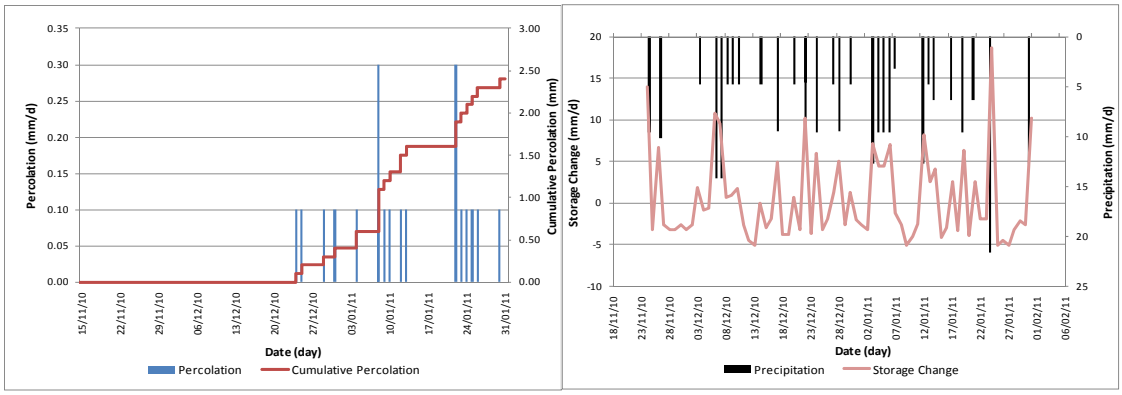

Figure 4 Percolation measured at UNESCO-IHE laboratory (left); Weighing balance measurement result at UNESCO-IHE Laboratory (right)

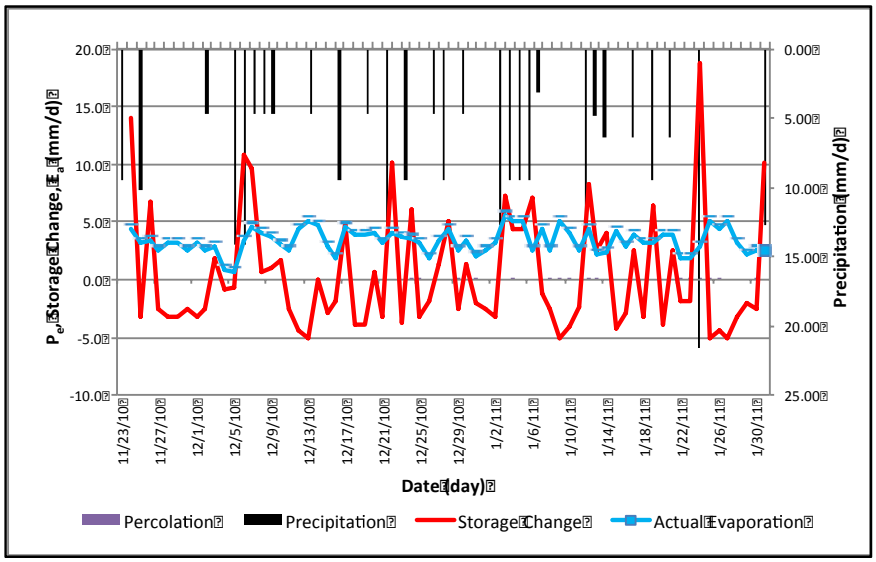

Figure 5 Water balance components and actual evapotranspiration

Water Balance Calculation

Water balance calculation is performed to determine actual evaporation in the laboratory. Actual evapotranspiration calculated using weighing balance is believed to be the most accurate actual evapotranspiration calculation. The main components in the water balance calculation are storage change determined by weighing change, precipitation and percolation water (see Figure 5). Actual evapotranspiration in the laboratory is 0.6-5.5 mm/d, thus the average of actual evapotranspiration is 3.4 mm/d. The actual evapotranspiration in the laboratory in some dates is higher than potential evapotranspiration calculated using Penman-Monteith formula (Figure 2) but the average of actual evapotranspiration is lower than the potential evapotranspiration (3.6 mm/d). The higher actual evapotranspiration causes the water inside the lysimeter evaporated fast. Thus, this is the reason why the design precipitation pattern using Rotterdam data for summer condition is not sufficient to provide adequate water for plants and had to be adjusted in January.

HYDRUS-1D Modeling

The HYDRUS-1D modelling has been divided into three parts. The first part is the calibration process in which the observed soil moisture has been simulated using inverse modelling to obtain the soil parameters. The second part is the validation process and the last part is the complete simulation from November to January. Calibration has been done from first December to the end of December. Data measured in November are not complete due to device malfunction. Validation has been performed from first December to the end of January. Thus, the calibrated parameters are used to simulate the soil evaporation and transpiration fluxes for the whole period from November to January.

The HYDRUS-1D model used two layers of different soil materials. Sand, clay and silt soil properties were used as initial soil parameter based on grain size analysis. The upper part contains more sandy material compare with the bottom part which has more clay material. The root depth is observed 5 cm depth. Initial soil moisture is obtained from the soil moisture sensors. Root distribution is one for the surface and it is decreasing to zero in the depth more than 5 cm. Initial soil moisture is between 0.22 (m^3/m^3) at the surface to 0.38 (m^3/m^3) at the bottom. The calibration processes used data from soil moisture sensor port 1 and port 5.

The calibration result is good and the R^2 for this calibration is 0.94. Simulation results for port 5 show that the observed values and simulated values are in good agreement except at the end of the simulation period. Simulation results for port 1 shows that the model was not able to capture some peak values although the recession limbs from model and observed fit. Percolation value can be used also for model calibration. Total percolation from the model is 0.1 mm while total observed percolation is 0.4 mm. The percolation values are not slightly different between simulated and observed. The validation result is good with R^2=0.89. The validation result is acceptable although the R^2 value is decreasing from 0.94 to 0.89 (see Figure 6). Some peak values were not captured by the model in port 1. Overall, the calibration and validation results are good and acceptable.

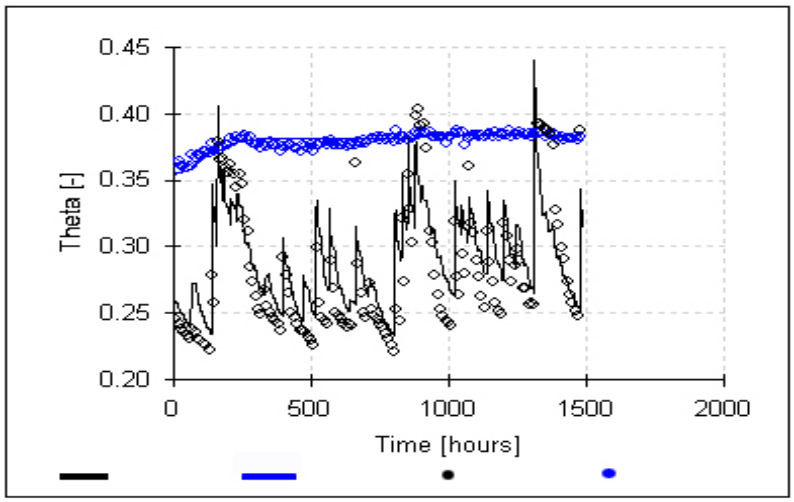

Figure 6 HYDRUS-1D model validation result

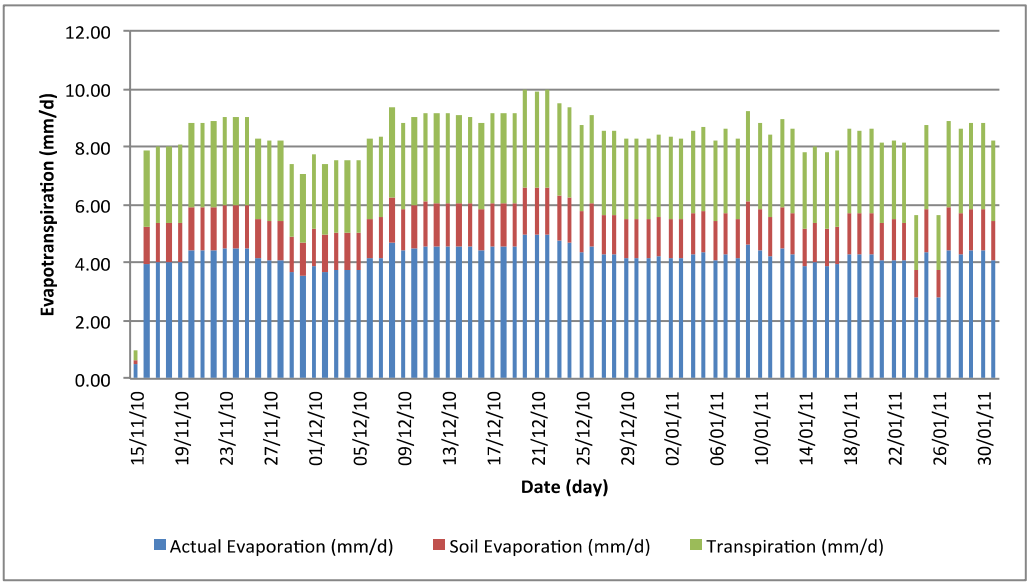

Figure 7 Laboratory evapotranspiration from HYDRUS-1D modelling

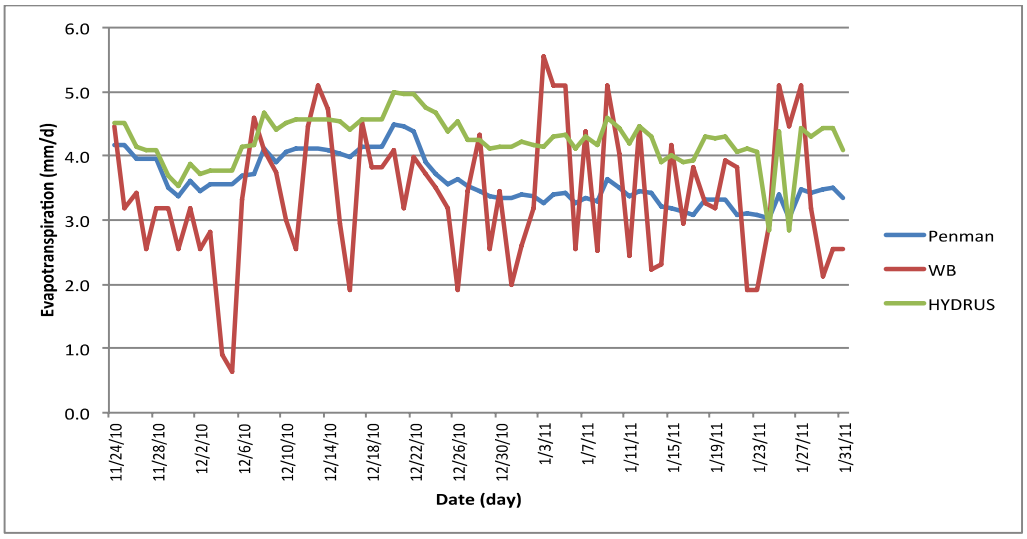

Figure 8 Evapotranspiration comparisson

The HYDRUS-1D model also can simulate the actual evapotranspiration rate, which is the sum of soil evapotranspiration and evapotranspiration from root water uptake based on FAO crop model (see Figure 7). The simulation period starts from 15 November 2010 to 31 January 2011. Average evapotranspiration is 4.2 mm/d for actual evapotranspiration, 1.4 mm/d for soil evaporation and 2.8 mm/d for transpiration. Evapotranspiration result from the HYDRUS-1D model is relatively higher compare to the water balance model and the Penman-Monteith. Average actual evapotranspiration from the water balance and the Penman-Monteith simulation is 3.4 mm/d and 3.6 mm/d respectively. The overestimate result from HYDRUS-1D model probably was affected by the HYDRUS-1D climate input data. Model time step is hourly but climatology data use daily input values. Thus the hourly input values for radiation and windspeed need to be multiplied by 24 hours. However, daily evapotranspiration calculation from those three methods shows that Penman-Monteith and HYDRUS-1D model have same pattern while the fluctuative of

evapotranspiration from water balance model is influenced by storage changes in the soil (see Figure 8).

Determination of Evapotranspiration Effect

Stable isotopes (^{2}H and ^{18}O) have been used to analyze the effect of evapotranspiration process. The results from water samples in the lab plotted against Global Meteoric Water Line (GMWL) are shown in Figure 9. All delta isotope values are based on IAEA VSMOW.

As expected, the isotope results show that the water inside the lysimeter is affected by soil evaporation since transpiration does not changing the isotopic composition in the soil water. The concept is when the water is transported between roots and leaves, the isotopic composition is remaining the same not changing until it reaches the leaves (Ehleringer and Dawson, 1992; Gat, 2010; Kendall and McDonnell, 1998; Riley et al., 2002; Tang and Feng, 2001; Williams et al., 2004). In the other hands, soil evaporation makes isotope composition in the soil water changing. Soil evaporation makes the evaporation line deviated from the GMWL and it creates an evaporation line with R^2=0.987 (Figure 9). The evaporation line has a slope of 3.65 and an intercept of -19.74‰ which is lower than GMWL. This evaporation line shows that kinetic enrichment of ^{18}O in evaporating water is more than ^{2}H. Water in the upper part has higher evaporation rates compared to the water in the lowest part of the soil. Evaporation makes the isotope composition in the water heavier. Precipitation, port 5 and some of the samples in port 4 are laying on the GMWL. This means that evaporation has a little effect in port 4 and 5 (depth 26.4 cm and 33.3 cm respectively).

The effect of evaporation in the soil can be determined by plotting the isotopes values against the depth (see Figure 10). Heavy value of ^{2}H and ^{18}O appears at a depth of 6.6, 13.3, and 20 cm and the heaviest value occurs at the depth of 20 cm from the soil surface. It means that evaporation has an effect until 20 cm depth and maximum value at 20 cm depth is called drying front. This process is caused by kinetic effects of diffusion (Kendall and McDonnell, 1998; Clark and Fritz, 1997). The shape of this profile is performed by isotope diffusion downward and upward capillary flow. The shape from surface to 20 cm depth is performed by vapour diffusion and shape from 20 cm depth below is performed by downward diffusion of isotope or capillary flow upward. Percolation isotope values are heavier compared with isotope values in the bottom part. This phenomenon is unusual and can be explained by evaporation process inside percolation device because this device is not air resistant or mixing water with the water from the upper part of the soil.

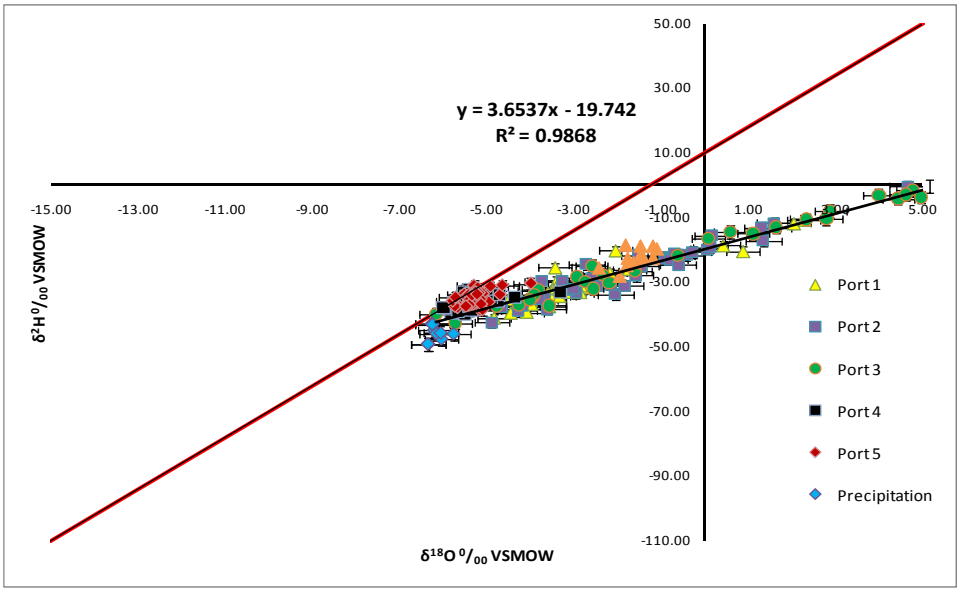

Figure 9 Isotope measurements in the Laboratory

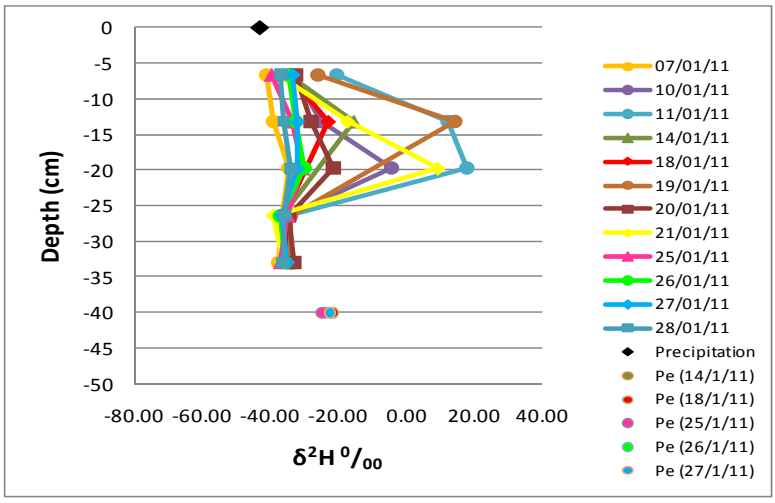

Figure 10 ^{2}H and values in relation with depth at UNESCO-IHE laboratory

CONCLUDING REMARKS

Hydrometric measurements are used to investigate the water fluxes in the vadoze zone in the UNESCO-IHE laboratory. All of the water fluxes components such as precipitation, percolation, evapotranspiration, and soil storage change in the vadoze zone are measured directly using hydrometric measurements techniques. Soil moisture measurements indicated that the soil types inside the lysimeter in the laboratory are sandy, silt and clay. Wet sieving analysis supports this soil types. Total percolation in the laboratory is small, 2.4 mm due to higher evapotranspiration rate and clay material.

Climate measurements inside the laboratory seem to have a good result. Measurement height is the sensitive parameter in Penman-Monteith method. Therefore, the Penman-Monteith calculation did not use the simplified formula because the measurements heights of radiation and windspeed are 20 cm from the lysimeter surface. Average evapotranspiration calculated using Penman-Monteith (3.6 mm/d) is higher than evapotranspiration calculated using water balance method. It is correct since Penman-Moenteith calculate the potential evapotranspiration and water balance calculate the actual evapotranspiration. Therefore, the climate conditions in the laboratory represents the summer situations like in the field.

HYDRUS-1D model was used to simulate the water fluxes inside the lysimeters with assumption no lateral flow and runoff. Interception was included in the HYDRUS-1D calculation. There was good agreement between HYDRUS-1D model and hydrometric measurements using soil moisture data and percolation. Model calibration is acceptable with R^2 0.94. Percolation result from the model is also supporting this calibration process. Percolation from the model is 0.1 mm and percolation measured from drain device is 0.4 mm.

Environmental isotopes (^{18}O and ^{2}H) have proved to be a useful tool to investigate the water fluxes in the vadoze zone. Environmental isotope analysis shows that higher evapotranspiration rate is occurring inside the lysimeter due to higher temperature inside UNESCO-IHE laboratory. It proves that temperature is the main factor triggering fractionation processes since the temperature in the laboratory is representing the summer condition. The fractionation process in the laboratory creates an evaporation line with R^2=0.98. The evaporation line has slope of 3.65 and intercept -19.74‰ which is lower than the GMWL.

Environmental isotopes can successfully describe the soil evaporation process in the soil water after plotted against the deep. The heavier values of ^{2}H and ^{18}O appeared at a depth of 6.6, 13.3, and 20 cm and the heaviest value occurs at the depth 20 cm from soil surface. It means that soil evaporation has an effect until 20 cm depth and maximum value at 20 cm depth is called drying front.

Evapotranspiration analysis has been carried out using water balance method, Penman-Monteith calculation, and HYDRUS-1D modelling. Penman-Monteith and HYDRUS-1D model have same pattern while the fluctuative of evapotranspiration from water balance model is influenced by storage changes in the soil. The average of actual evapotranspiration is 3.4 mm/d, 3.6 mm/d and 4.2 mm/d calculated using water balance, Penman-Monteith and HYDRUS-1D model respectively. Actual evapotranspiration calculation using water balance is believed to be the most accurate method to calculate the actual

evapotranspiration because this method calculates the water loosing inside the lysimeter directly. Penman-Monteith method calculates the potential evapotranspiration, thus it is correct that Penman-Monteith has higher result compared with water balance. The result from HYDRUS-1D is overestimate due to data input conversion.

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