

Accuracy of water flux measuring with a passive-wick water sampler in comparison to a high-precision gravitation lysimeter

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Zusammenfassung

In den letzten Jahren zeichnet sich in Europa ein zunehmender Trend bezüglich des Einsatzes von Lysimetern zur Messung von Wasser- und Stoffflüssen in Böden ab. Allerdings sind diese direkten Messtechniken im Vergleich zu indirekten Messmethoden relativ kostenintensiv. Besonders in den USA ist man darum bemüht, Wasser- und Stoffflüsse ebenfalls direkt zu messen, dabei aber erheblich kostengünstigere Messgeräte, wie z.B. wick sampler (Dochtsammler) zu entwickeln und einzusetzen. Im Mittelpunkt des Beitrages steht der mehrjährige Vergleich bezüglich der exakten Erfassung der Sickerwassermengen, die zum einen mit wick samplern vom Typ DDM und zum anderen mit technisch hochentwickelten wägbaren Gravitationslysimetern gemessen wurden. Die Abweichungen zwischen den beiden Systemen betragen bei der Sickerwassermenge weniger als 8 %. Es wurde festgestellt, dass wick sampler eine Alternative zu herkömmlich genutzten Gravitationslysimetern auf Standorten mit Grundwasserflurabständen > 2 m sind.

Schlagwörter: Dochtsammler, wägbares Gravitationslysimeter, Sickerwassermenge

Summary

In Europe the use of direct lysimetry methods for measuring water and solute fluxes in soils increased in the recent years. This technique ensures reliable drainage data, but it requires relatively high investment and maintenance expenses. Other research groups, especially in the USA, developed alternative techniques – passive-wick water samplers - that can directly measure water and solute fluxes without great expenses. In this paper we compare the function of a passive-wick sampler, especially the deep drainage meter type – DDM – with a high sophisticated weighable gravitation lysimeter regarding accuracy of seepage water measurement under field conditions in Germany for a time period of three years. Despite the detected inhomogeneities relating the seepage formation process the differences of seepage amount between the two systems ranged during the experimental period of less than 8%. The DDM is in comparison to the tested gravitation lysimeter a cost-effective measuring system. It delivers reliable measuring data regarding the seepage water quantity in sandy soils with adequate groundwater levels > 2 m.

Keywords: wick sampler, weighable gravitation lysimeter, seepage water quantity

Introduction

A suite of methods for measuring water and solute flux in and below the root zone have been developed over the years (WEIHERMUELLER et al. 2007). In the past few years, various research groups have initiated the development of alternative techniques that can directly measure water and chemical fluxes without great expense. The wick (fixed tension) water samplers (a special type of fluxmeter) control water pressure (or tension) at the drainage interface. Basically, they maintain a fixed tension on the soil using an inert wicking material, such as fiber-glass or rock wool. GEE et al. (2002, 2003) have further modified the wick lysimeter to capture both the water and solute fluxes using a solution sampling scheme that simultaneously takes solution samples for chemical analysis at the same point and time that flux is monitored.

Large weighable lysimeters and fluxmeters are both an appropriate tool to measure water and solute fluxes directly (MEISSNER et al. 2008). They considerably differ concerning the constructive complexity which is also reflected to the expenses of both measurement systems. The

fluxmeter can be assigned to the more simple construction types. By contrast, weighable lysimeters are part of high sophisticated technology and much more expensive than fluxmeters. Weighable gravitation lysimeter and passive-wick fluxmeter are widely used in practice. Both methods have pros and cons.

Therefore, the objective of this paper is

- to compare the function of a passive-wick water sampler with a high sophisticated weighable gravitation lysimeter regarding accuracy of measuring the amount of seepage water under field conditions in Germany and
- to give recommendations for practical applicability of each method.

Material and methods

Passive-wick water sampler design

The water fluxmeter of GEE et al. (2002) is essentially a wick-fluxmeter that can be installed below an active root zone to monitor drainage. They called this type deep draina-

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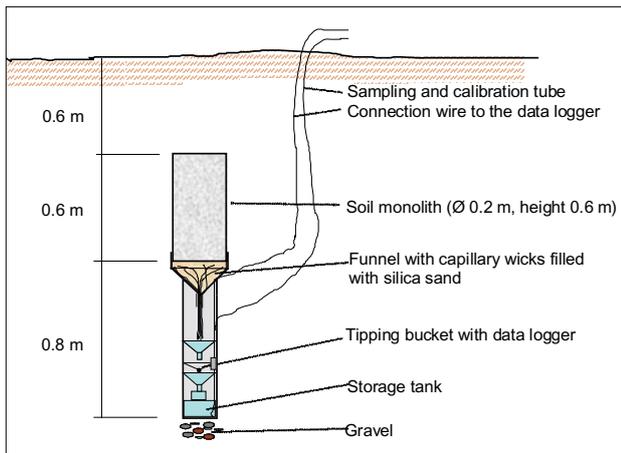


Figure 1: Schematic of DDM - water fluxmeter

ge meter (DDM; Figure 1). Capillary wick samplers or wick lysimeters are sampling devices which sample soil water by the gravitational potential (WEIHERMÜLLER et al. 2007) using an inert wick material such as fiberglass (HOLDER et al. 1991) or rock wool (BEN-GAL and SHANI 2002). Fiberglass wicks were used in the DDM. By applying a hanging water column using wicks, the drainage water is pulled out of the sampling device while the lower soil boundary is maintained at a pressure less than atmospheric resulting in an unsaturated soil (GEE et al. 2004). The DDM unit is compact, durable, and can be purchased commercially from Sledge Sales Consulting, Dayton, Oregon, USA.

Lysimeter design

Figure 2a shows a schematic of a weighable gravitation lysimeter equipped to measure water and solute flux.

This type of lysimeter has a surface area of 1.0 m² and a total depth of 2.0 m. The soil column in the stainless steel lysimeter vessel was monolithically extracted. The lower boundary was segmented to obtain information on the spatial heterogeneity of the water fluxes. Therefore, the lysimeter bottom is divided into 8 sections (Figure 2b). The internal segments are bordered by stainless steel walls of 0.2 m in height. Every segment is connected with a single tipping bucket to measure the amount of seepage water. Seepage of each segment is collected in an individual storage bin from which water samples can be taken to additionally quantification of seepage and for chemical analysis.

The lysimeter was equipped with three shear stress cells, which are placed on top of stainless steel pedestals. Even at a total lysimeter mass of 4.000 to 4.500 kg this weighing system registers mass (weight) changes of up to 30 g (MEISSNER et al. 2007). Tensiometers, TDR (time-domain reflectometry) probes, thermometers and suction cups are installed at depths of 0.30 m, 0.90 m and 1.50 m. All measured data are stored in a data-logger, whose recording interval is chosen by the user.

Site and soil description

We tested two water fluxmeters (DDM 1 and DDM 2) and two gravitation lysimeters (numbers 211 and 212). The test sites are located in the Federal State of Saxony-Anhalt, Germany (Figure 3). Lysimeter 211 and 212 and the DDM 2 are located at the Helmholtz-UFZ lysimeter station at Falkenberg (52° 51' N; 11° 48' E). The DDM 1 is located at the small experimental catchment area "Schaugraben" (52° 46' N; 11° 46' E). The Schaugraben is tributary of the Elbe River in north-east Germany covering an area of about 2,500 ha. This catchment is about 10 km away in south-west direction from the Helmholtz-UFZ lysimeter station and matches to

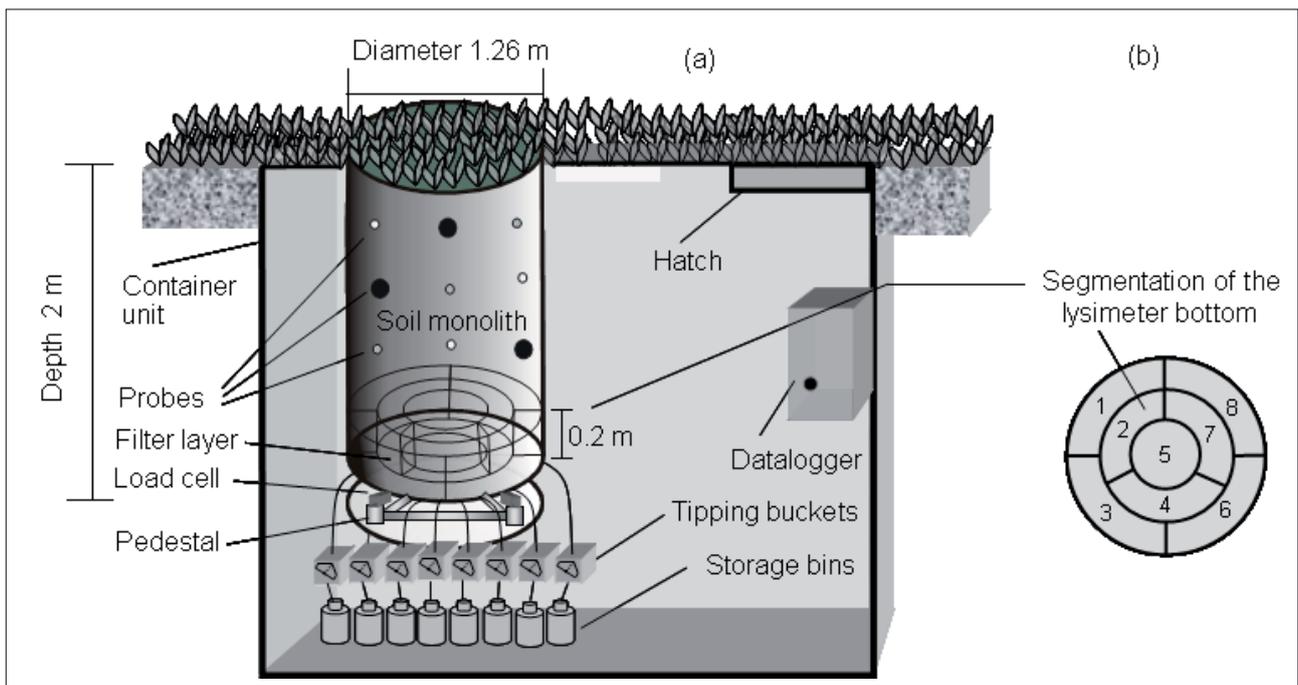


Figure 2: Scheme of a weighable gravitation lysimeter (a) with tipping buckets and (b) segmentation of the lysimeter bottom

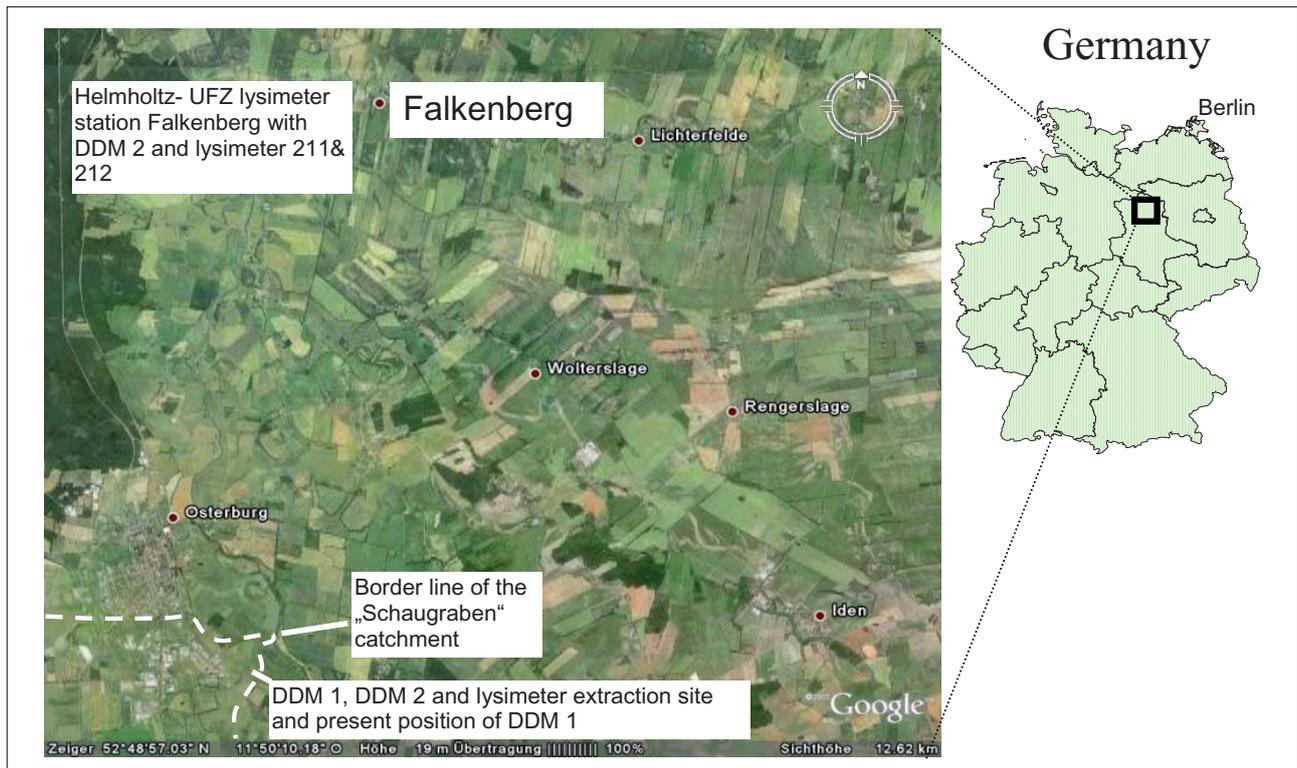


Figure 3: Geographical position of the DDM – sites, the gravitation lysimeter site and the extraction site of both

the location of the lysimeter in both meteorological factors and pedological parameters (MEISSNER et al. 2002a, CHAMBERS et al. 2006). The test sites are climatically allocated to the transition zone of the moderate climate. Precipitation averages to 536 mm per year (1986-2001; Falkenberg, Germany), with maximum precipitation occurring during June and July. Long-term mean evapotranspiration was 495 mm (1986-2001) and mean annual temperatures ranged from 7.3 to 10 °C (1986-2001).

Furthermore, we used an identical soil from the experimental catchment “Schaugraben” (52° 46' N; 11° 46' E) for filling DDM 2. The monoliths of lysimeter 211 and 212 as well as the site from which the soil of DDM 2 originated were characterized as Dystric Cambisol according to FAO soil classification (FAO 1990).

Installation of the measuring technique

In June 2003 we started with the installation of the DDM 1 at the “Schaugraben” field site. We installed the second fluxmeter (DDM 2) in the same year at the Helmholtz-UFZ lysimeter station at Falkenberg in neighbourhood (approximately 20 m) to the gravitation lysimeters. It is a precondition for using of the DDM that the groundwater table is durably > 2 m below the soil surface according to its construction. The groundwater level of the Schaugraben site (DDM 1) is strongly influenced by the adjacent ditch system. Therefore, a groundwater level of ≤ 2 m can not be always excluded, especially during wet periods. The DDM 2 (installed at Helmholtz- UFZ lysimeter station) was not affected by ascending groundwater table.

The two lysimeter vessels were monolithically filled in September 2001 at a grassland site in the Schaugraben catchment (52° 46' N; 11° 46' E). The cylindrical lysimeter monolith was collected by a newly developed extraction technology (MEISSNER et al. 2007).

The vegetation cover of both lysimeters and fluxmeters matched to the grassland vegetation at the extraction site. The recent agricultural management regimes of the lysimeters and the fluxmeters were similar but not equal. The lysimeters were managed as a typical regional grassland with mineral fertilization and 3 cuts per year. They got since 2001 a yearly fertilizer application rate of 20 gm⁻² nitrogen, 2.5 gm⁻² phosphorus and 11 gm⁻² potassium. Since installation of the fluxmeters the extraction site (DDM1) as well as the site at the Helmholtz- UFZ lysimeter station Falkenberg (DDM2) were not fertilized.

The amount of seepage water was continuously measured at the lysimeters. Data from both fluxmeters were collected once per week.

Results and discussion

Precipitation at the “Schaugraben” catchment and at the UFZ lysimeter station

Figure 4 presents the precipitation measured at the “Schaugraben” catchment and at the Helmholtz- UFZ lysimeter station at Falkenberg. As a result of three years measurements (May 2005 – April 2007) the precipitation amount at the in situ site (Schaugraben) exceed in total the amount

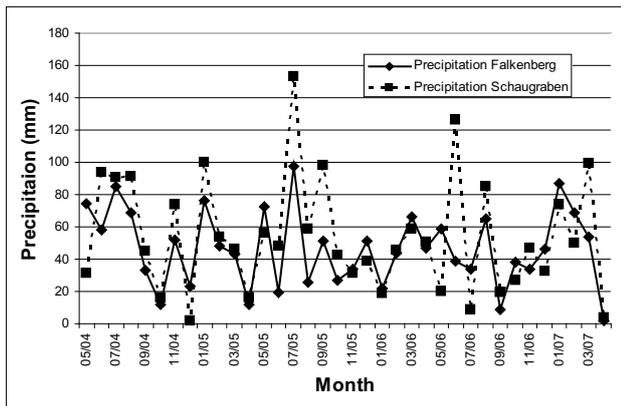


Figure 4: Precipitation at the Schaugraben catchment and at the Helmholtz- UFZ lysimeter station Falkenberg

of Falkenberg by approximately 276.5 mm. These differences were probably a result of mesoscale climate variations mainly caused by extreme events (e.g. thunderstorm with intense rain). For the two precipitation time series statistical comparisons (analysis of variance) were carried out (not shown). We didn't find statistically significant differences between the main-effects year, as well as hydrological winter or summer half year, and site. Therefore, both time series can be compared directly.

Seepage measured by DDM and lysimeter

The amount of seepage water measured by DDM and lysimeter is presented in Figure 5. Although DDM 1 and DDM 2 were installed at different sites, the measured amounts of seepage (weekly data) were closely correlated ($r_s = 0.82$). A total seepage amount of approximately 280.0 mm was measured at DDM 1 during the experiment. DDM 2 situated at Falkenberg showed in the reference period a slightly smaller level of seepage (in total 253.8 mm). This can be mainly explained by the lower level of precipitation at this site (see 3.2). The total amount of precipitation at Falkenberg fell below the value of the "Schaugraben" by 276.5 mm (between May 2004 until April 2007). The starting point of seepage formation was almost comparable. At the beginning of the experiment in May 2004 in both DDM's seepage occurred but the amounts differed. In the year 2005 the seepage formation began at DDM 1 two weeks earlier than at DDM

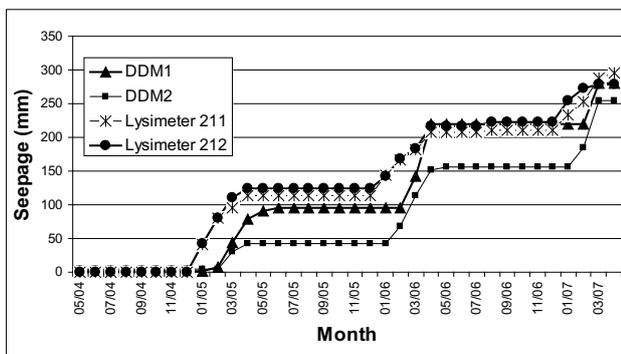


Figure 5: Seepage amount of DDM and lysimeter (sum curves)

2. But DDM 2 starts approximately 4 weeks before DDM 1 in the seepage periods 2006 and 2007. Seepage formation at DDM 1 lasted in 2005 four weeks longer than at DDM 2. In 2006, the discharge period of DDM 1 was compared with DDM 2 four weeks earlier completed. The seepage formation of both DDM's was completed in March 2007. At DDM 1 the natural site conditions were probably earlier reached in relation to the top soil compaction before the DDM installation. The effects observed at DDM 2 in 2005 can be ascribed to the installation which was completed in December 2003. Here, a longer period was needed for the soil consolidation to achieve the natural seepage regime. It is assumed that the soil physical parameters of the original site (bulk density) weren't reached until yet. The soil might be less compacted and therefore the seepage process was promoted.

As expected, the seepage of both lysimeters 211 and 212 was closely correlated ($r_s = 0.88$). The total amount of seepage was almost comparable. After 3 years of observation the seepage of lysimeter 211 was in comparison to lysimeter 212 only 17 mm higher. The temporal pattern of seepage formation was also comparable for both lysimeters. Looking at the monthly seepage data both lysimeters can be regarded as replications.

After an investigation period of three years we measured only a comparatively small difference in the amount of seepage between DDM and lysimeter. The average annual amount of seepage measured by the lysimeter method was 96 mm and marginally exceeded that of DDM (89 mm). The total amount of seepage measured by DDM and lysimeter showed to a large extend congruence. The relative difference between the smallest (DDM 2 \approx 254 mm) and the highest amount (lysimeter 211 \approx 296 mm) was 42 mm during the investigation period (May 2004 – April 2007). The seepage volume of lysimeter 212 and DDM 1 was almost identical (279 mm and 280 mm, respectively) and ranged between the values of DDM 2 and lysimeter 211, respectively. This result was surprising because the high sophisticated measurement technology like a weighable lysimeter was opposed to a comparatively simple low cost system (DDM) and no distinct difference regarding the amount of seepage were detected.

A difference of both systems consists in the temporal pattern of seepage formation. In average of three years, there was a time lag of approximately 4 up to 8 weeks between the recharge periods in lysimeter and DDM. This effect was probably caused by the different construction design of DDM and lysimeter. Both systems lysimeter and DDM differ in surface area. The DDM was featured by capillary wicks, which are situated at the bottom of the soil column and inside the first funnel ending at 1.3 m below ground level. The fiberglass maintains a fixed tension due to the hanging water column on the soil (HOLDER et al. 1991). The lysimeter surface area of 1.0 m² was also regarded as precise for seepage collection, because it is sufficient to reduce edge effects. Therefore, a considerable difference regarding the amount of seepage measured by lysimeter and DDM shouldn't be expected. But it has to be kept in mind that the usage of disturbed soil or materials in the DDM will change the natural texture and the spatial heterogeneity

with adverse impact on the water flux like already shown in lysimeter experiments (WEIHERMÜLLER et al. 2007). According to the lysimeter construction its lower boundary was exposed to the atmospheric pressure, resulting in an evolution of a water-saturated zone at the bottom of the lysimeter. Seepage was only possible if the soil pores at boundary layer (filter layer) were saturated and pressure overcomes atmospheric pressure. Therefore, the deepest layer of the transition zone between lysimeter bottom and atmosphere stays saturated and contains a certain amount of residual water at the end of the seepage period due to the lack of a hydraulic potential which is necessary to drain this layer. If leachate occurs again in the upper soil horizons the pore space at the boundary layer is filled up. If the pore water pressure exceeds atmospheric pressure seepage restarts. Therefore, the soil water content inside the boundary layer of the lysimeter was probably higher than that of the DDM. Under similar conditions (soil and climate), only a fixed amount of seepage was formed during the hydrological winter half year. This leachate volume occurred regardless of the measuring system. It became earlier effective for seepage at the lysimeter because of the postulated higher residual water content compared with the in the DDM. It was assumed that the time lag between seepage period in lysimeter and DDM can be attributed to this effect.

Conclusions

No significant distinctions occurred in long term measurement of seepage formation between both a passive-wick water sampler (deep drainage meter –DDM type) and weighable gravitation lysimeter. Despite the detected inhomogeneities relating the seepage formation process the differences of seepage amount between the two systems differed during the experimental period of three years less than 8 %. This was even more astonishing when considering the distinct smaller surface area of the DDM (0.03 m²) in relation to the lysimeter (1.0 m²).

The DDM is in comparison to a conventional gravitation lysimeter a cost-effective measuring system. It delivers

reliable measuring data regarding the seepage water quantity in sandy soils with adequate groundwater levels > 2 m. Further research is necessary to test the DDM with more cohesive soils as well as the acceptability of the DDM to measure seepage water quality.

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