

Lysimeter research in Europe – technological developments and research strategies

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Abstract

Exact information about the soil water balance is needed to quantify water and solute transfer within the vadose zone. The monitoring of these fluxes is a big challenge because the results are the basis for answering a couple of questions regarding protection of groundwater, sustainable management of agriculture, mining or set aside industrial areas, reducing leachate loss from landfills or explain the fate of industrial harmful substances. In Europe, the use of direct lysimetry methods for measuring water and solute flows in soils has increased in the recent years. The combination of lysimeter studies with field experiments at different scales opens new possibilities for modelling and management of watersheds. The paper informs about a cutting technology for the undisturbed extraction of a soil monolith at different sites, which is compared to the most frequently used extraction procedures using X-ray tomography. The weighing precision of a 2 m deep lysimeter with a 1 m² cross-sectional area is demonstrated and shows that the direct measurement of dew, fog and rime is possible. New technical developments as well as strategies for further lysimeter research activities will be presented and discussed.

Key Words

Soil hydrology, lysimeter technique, soil monolith extraction, weighing precision, lysimeter development

Introduction

Different lysimeter types are used at research institutes, administration facilities as well as environmental service agencies. In the international literature, the term “lysimeter” is used for different objectives, e.g. suction cups, fluxmeters, etc. (Weihermueller *et al.* 2007). According to our understanding, it belongs to the direct methods to measure water and solute fluxes in soil. The design (required surface and length) depends mainly on the scientific question, the nature of vessel filling (disturbed or undisturbed), the lower boundary, and the location of installation. Small scale heterogeneity of a site will be averaged using a larger base area of the lysimeter. Furthermore, lysimeters with vegetation should represent the natural crop inventory and the maximal root penetration depth should be taken into account. Except for the generation of well defined recurrences of the same soil conditions, it is recommended to fill the lysimeter vessel monolithically. According to our knowledge, a large weighable lysimeter is the best method for obtaining reliable data about seepage water quantity and quality, but it involves significant investment and additional expenses for maintenance. Nevertheless, in Europe the use of direct lysimetry methods for measuring water and solute movement in soils increased in recent years (Lanthaler and Fank 2005). The aim of this paper is to inform about (i) technologies for the undisturbed extraction of a soil monolith at different sites during filling a lysimeter vessel of different sizes, (ii) the high accuracy of the lysimeter weighing technique and (iii) strategies regarding the development and use of lysimeter techniques.

Methods

Soil monolith extraction technology

Minimal disturbance of the soil monolith during extraction and subsequent filling of the lysimeter vessel is of critical importance for establishing flow and transport conditions comparable to natural field conditions. In the past, several methods were used to extract and fill lysimeter vessels vertically - including hand digging, employing sets of trihedral scaffolds with lifting blocks and ballast, or using heavy duty excavators, which could shear and cut large blocks of soil. More recently, technologies have been developed to extract cylindrical soil monoliths by using ramming equipment or screw presses. One of the great disadvantages of the mentioned methods is the compaction or settling of soil that occurs during the “hammering” or “pushing”. For this reason a new technology was developed, which cuts the outline of the soil monolith employing a rotary cutting system (Meissner *et al.* 2007). This procedure should avoid structural damages and substantially reduces the necessary technical expenditure during monolith extraction. The extraction site is only minimally affected, since the forces needed for cutting the soil monolith are small, due to reduced wall friction of the lysimeter vessel. This “cutting” technology has been used successfully for different soil

types (from peat to gravel to sand to clay and including contaminated sites) and for different lysimeter dimensions (surface area 0.1-2 m² and depths of 0.5-3.0 m).

Weighing precision

A key parameter of a lysimeter is its weighing precision – the higher it is, the better the resolution of the weight measurements. A high resolution makes it possible to chart seepage and evapotranspiration over short periods such as hours or less, while a low resolution only allows daily values. Instead of a mechanical weighing system, which is currently the most widely used technology, our new lysimeters are equipped with three shear-stress cells, which are placed on top of aluminium pedestals (Xiao *et al.* 2009). The shear-stress cells produce a current, which is proportional to the load. The current is then transformed into a digital signal using an A/D-converter, which is adjusted to record the mass of the lysimeter vessel with a resolution of 10 g. For routine work, the weight is registered every 10 s and then averaged for intervals of 10 min.

Results

Soil monolith extraction technology

For the evaluation of the different extraction technologies with respect to the potential disturbance of soil structure we applied the different techniques for the same soil type (Eutric Fluvisol). At natural site conditions, soil monoliths with the same size have been extracted with the “hammering”, the “pushing” and the “cutting” technology (Figure 1). The soil structure close to the vessel wall was recorded using X-ray tomography at a resolution of about 0.1 mm. The X-ray tomography images showed that the “hammering” procedure irreversibly influences the structure of the soil monolith; the “pushing” technology reduces the disturbances but is connected with structural damages around the excavation pit. The “cutting” technology influenced only the edge between soil monolith and the lysimeter vessel and reduced damages at the extraction site essentially. There are different cutting devices for the individual size of the lysimeter vessel available.

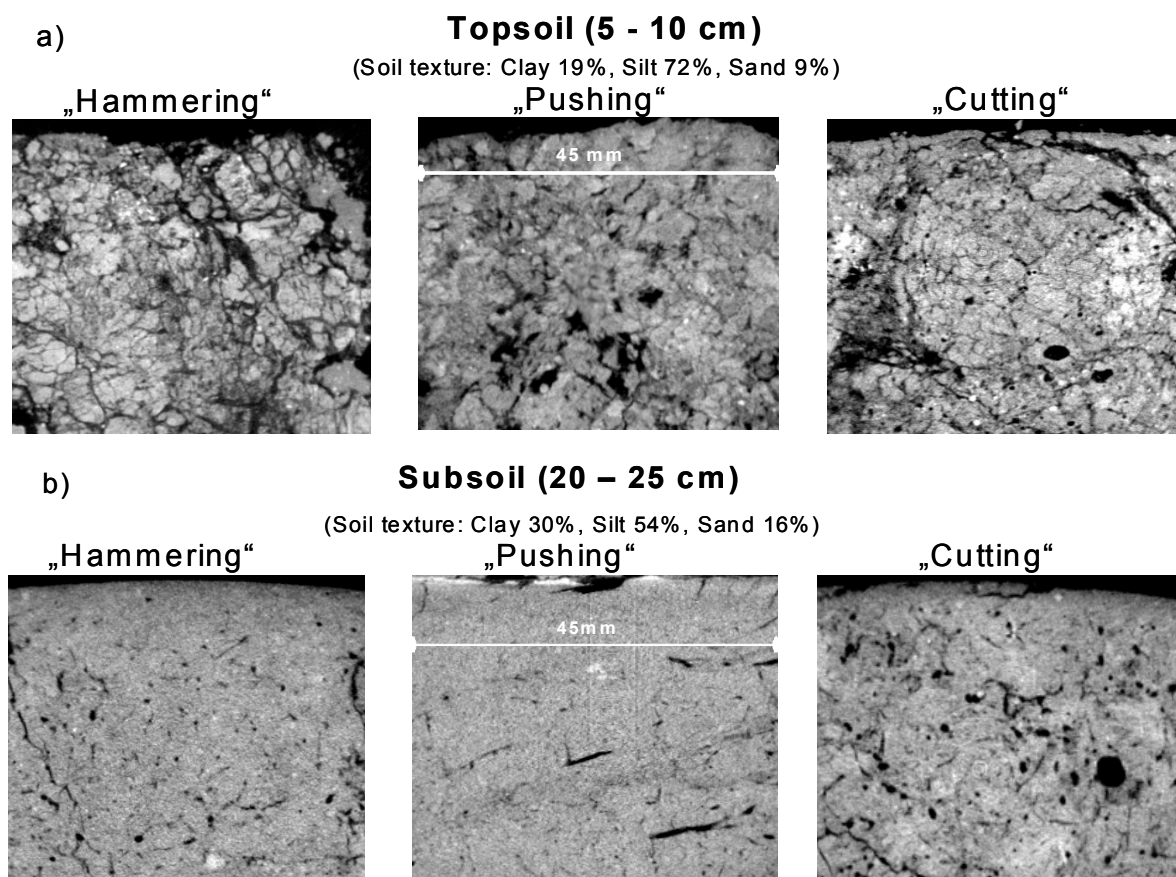


Figure 1. X-ray tomography images during testing of different soil monolith extraction techniques for the soil type „Eutric Fluvisol“ at a floodplain site; a) topsoil, b) subsoil.

Weighing precision

Tests were carried out to determine the weighing precision of a 2 m deep lysimeter with a 1 m² cross-sectional area and a total mass of 3500 to 3850 kg, depending on the soil water content. Weights of 500, 200, 100, 50, 20, and 10 g were placed at the centre of the lysimeter as well as at 10, 23, 55, 77, and 100 cm along two perpendicular lines through the centre of the lysimeter. Mass changes as small as 20 g, which is equivalent here to water gain or loss of 0.02 mm, can be measured with good accuracy and stability under favourable environmental conditions (low wind speed, relatively constant temperature) (Figure 2). This precision does not depend on the position of the weights at the lysimeter where the mass change occurs. This lysimeter type makes it possible to register mass input by dew, fog or rime and it also permits a very accurate calculation of the actual evapotranspiration.

Special experiments with this lysimeter type showed that dewfall makes a notable contribution to the water balance of crops and grass in northern Germany, since it amounted to 5.5 -6.9% of the annual and, several times during the study period, to > 20% of the monthly precipitation. The dewfall study also illustrates that the vegetation cover affects dew formation. There was consistently more dewfall on covered than on bare lysimeters. In addition, dewfall increased with crop growth, reflecting the rising frequency and amount of dewfall on growing crops compared to a continuous grass cover, and then fell again after harvest.

A high-resolution weighing technique enables detailed investigations of the water balance, forming the basis for a highly accurate calculation of the solute balance and for modelling hydrologic processes. Furthermore, the newly developed experimental setup allows a scenario simulation of topical climatic and hydrologic questions, e.g., global warming and its impact on the water and solute balance, the influence of dew, fog and rime on the establishment of a vegetation cover in arid areas or the transport of contaminants during heavy rainfall following severe drying-up of the soil profile.

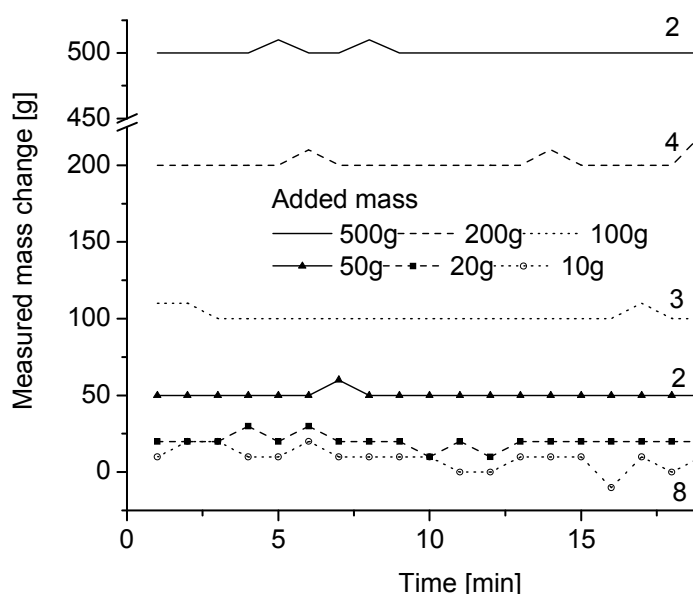


Figure 2. Recorded mass change over a 20 min period after the addition of different weights for the gravitation lysimeter. The values near the lines indicate the number of deviations from the true mass change.

Conclusion

In Europe, lysimeters of various designs are used to quantify diffuse pollution of water resources and to improve modelling and management of watersheds. There is a tendency to develop new lysimeter techniques, especially regarding the extraction of undisturbed soil monoliths of different sizes, the implementation of a high-resolution weighing technology, the development of containerized lysimeter stations as well as specific lysimeter types (groundwater lysimeter, fen lysimeter) and the improvement of technical details as the lower boundary condition and a technology for sinking lysimeters during field work

on the ground (Meissner *et al.* 2008). Gravitation lysimeter vessels are also used to test non-invasive techniques (electrical resistivity tomography –ERT, ground penetrating radar – GPR) to characterize water and solute fluxes in soils. Interesting is also a new retrieval technology for intact soil monoliths from lysimeter vessels which allows the immediate dissection of the soil column into slices and its investigation. The new extraction techniques opens new avenues for a direct comparison of state variables and fluxes measured in lysimeters with those measured directly in the field. This is because after the extraction of the monolith a cylindrical cavity remains where the surrounding soil is not affected by the sampling procedure. The walls of this cavity can be analyzed to get valuable information about the structure and layering of the soil inside the lysimeter. Moreover, this cavity can be equipped with equivalent sensors systems as the lysimeter. This monitoring concept is actually realized within the “TERENO” (TERrestrial ENvironmental Observatories) project at the UFZ. “TERENO” is a research initiative of the Helmholtz Association with the aim to establish observation platforms in different climate and management sensitive regions of Germany and to investigate the behaviour of terrestrial systems in response to changing environmental conditions.

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