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LYSIMETER - A UNIQUE TOOL FOR MONITORING THE INTERACTIONS AMONG THE COMPONENTS OF ENVIRONMENT

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Abstract

Modern lysimeter facilities in connection with meteorological stations allow monitoring and evaluation of mutual basic components of the environment, such as water, air, soil and vegetation. Water is the most important component of the ecosystem and the component which connects all the other components. Therefore, we need to know the basic distribution and water balance in the different components of the environment to be able to interpret some processes in nature. Rainfall, which is the primary source of vital processes in the soil, is formed in the air. The amount of precipitation that gets into the soil and into the groundwater is affected by weather conditions. Primary distribution of rainwater is divided between infiltration, surface runoff, transpiration and evapotranspiration. The amount of water infiltrated into the soil and then evaporated by solar activity or activities of plants can be identified primarily by monitoring changes in weight. For this monitoring we use weighable lysimeter. This equipment with the monolith size of surface area 1 m^2 and the depth of 1.5 m is able to follow online updates of weight of the 2 ton body with an accuracy of 100 g. When we add to quantification of leakages through the bottom layer, we obtain a comprehensive record of rainfall at the time in the natural environment of the individual components. The obtained data can be further interpreted in terms of the needs of hydrology, agriculture, and environmental studies, and according to the purpose and objectives for which we want to use them.

Keywords: agriculture; complex study of ecosystems; environmental monitoring; hydrology; lysimeter research; modern field technologies in ecology; water distribution and balance.

1. Introduction

In countries of Western Europe and especially in Germany, there was a lot of money invested into development of lysimeter research. It is almost not possible to compare current lysimeters and those, which were manufactured in previous century.

Based on principles of modern technologies, materials and computer science the new Hi-tech equipment were developed. Nowadays the lysimeter research expands as interesting and progressive method for complex study of ecosystems in their natural conditions. Aim of this article is to inform about the modern lysimeter technique and its application possibilities in assessment of the state of environment via participation in ecosystem research.

2. Analysis of research and puplications

Lysimeters have been used for nearly three centuries to study water percolation through soil. Today, lysimeter experiments are most commonly used for scientific studies of the fate and movement of water, gases, pesticides, nutrients, tracers, trace elements, heavy metals, metalloids, radionuclides, viruses or bacteria [3].

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 [5]. 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 [10]. Except for the generation of well defined recurrences of the same soil conditions, it is recommended to fill the lysimeter vessel monolithically. A large weighable lysimeter is the best method to obtain reliable data about quantity and quality of the seepage water, but this requires significant investment and additional expenses for facility maintenance [11].

Thus, lysimeters not only function as in situ water and solute quality assessing tools, but are of significant importance in a variety of fields such as agricultural management, including meteorology, agronomy, agriculture, ecosystems and environment, applied geochemistry, environmental pollution, environmental radioactivity, forest ecology and management, forest meteorology, hydrology, soil and tillage research, biochemistry waste management and water quality management [4].

3. Technology description

First of all, in compare to the previous years, there is a significant difference in proportions of lysimeter vessel. Nowadays, the representative lysimeter can be characterised by diameter of 1.1 m and depth of 1.5 m. Over the years, the research has shown that for the precise imitation of natural soil conditions it is necessary to have sufficient volume of soil and surface area. Thus, it can cover all of the non-standard soil structures and in homogeneities, as they commonly occur in the nature. The largest soil monolith is the ideal way. But this idea has its technical and economical limitations. So that the mentioned proportions represent the compromise between the requirements of research and economical capacity [1].

Lysimeter experiments are mostly used for scientific studies of the fate and movement of water, pesticides, salts/nutrients, tracers, trace elements and heavy metals.

Lysimeters have been used to study water percolation through and evaporation from soil and waste, and more recently to evaluate solute transport models and monitor the fate and mobility of contaminants.

Second requirement asks the undisturbed soil monolith even in the bigger sizes. In the past this was not possible, but current technology allows it. Patented excavated technology has been developed in Germany.

Third and the most important requirement of research it the ability to weigh the soil monolith with sufficient accuracy. It is the must for the soil water balance. But for a long time this was not possible from the point of view of engineering and technologies. Today the lysimeters are able to weigh the soil monolith with weight of 2-5 tons and the accuracy of this process is 100 grams. Sensitivity like this allows to detect precipitation in amount of 0.01 mm per $1m^2$. Which means even the dew can be detected and considered into the total water balance. Fig. 1 depicts a scheme example of modern lysimeter station with two soil monoliths [2].

Lysimeter station is designed as a sealed container which is made of PE-HD material with the layer structure. It is absolutely resistant to water. In this kind of container there are dry conditions for work and good access to measuring devices as well. It also allows simple and effective installation of the whole station into open field. Container consists of working shaft for operators and the installation shafts for one to four soil monoliths [6].

Soil monoliths are installed onto precise weighing system, which is connected to data-logger and display for quick visualisation of current monolith weigh [10].

Monolith is equipped with various probes to determine the soil temperature, soil moisture content and soil conductivity as well as tensiometers and sampling probes to obtain the soil solution from different layers. The sampled solution can be connected to analytical devices to get the continual data about the target nutrient or contaminant content.

Bottom of lysimeter vessel is filled with gravel of different size to create the drainage layer. Amount of percolate water throughout this layer is exactly determined by the tipping counter. It is also possible to sample it for the quality analysis. Surface run off can be captured in a collar on the top of lysimeter and recorded by tipping counter. This set up enable to obtain complete data set about the water balance and water distribution in system based on the change of monolith weigh (ΔW) [11]. More details and the formula for this process are visible in Fig. 1.

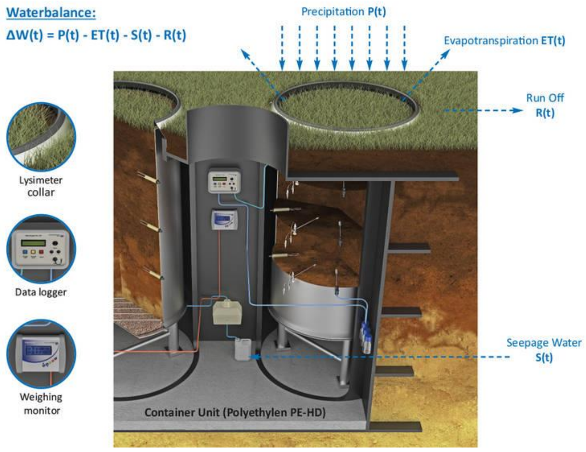

Fig. 1. Lysimeter station scheme

Lysimeter can be equipped with the control system of lower boundary conditions. It helps to keep the stabile level of saturated layer at the bottom of lysimeter and in the same time it imitates the natural moisture and pressure conditions according to the real parameters of reference soil. This system can be replaced by the system of artificial regulation of water level in saturated zone [9].

The same temperature gradient in monolith and surrounding soil is provided by the heat exchanger circle. Water is the medium which transfers the heat and balances the temperature in both parts of system.

It is forced by pump to circulate between the monolith drainage layer and surrounding soil.

Meteorology station is usually a common part of lysimeter station. It records weather parameters and it allows to study the relationships between the climate and the target system.

To cover the complete biological research approach it is eligible to add plant physiology measurements. Water transpiration, photosynthesis rate, plant biomass increment, root development, leaf area and similar measurements contribute to complex monitoring of the whole system of soil-plant-atmosphere. Different crops can be involved into lysimeter studies - grasslands, agricultural crops, including fruit and vegetable, even the trees. Another research approach is the study of dissolved substances in soil water, their space and time distribution in ecosystem. They can be the important plant nutrients but the contaminants as well [4].

During the preparatory phase of lysimeter station establishment, it is important to obtain the undisturbed soil monolith. It has to be settled into lysimeter vessel without the preferential ways for the seepage water percolation into the drainage layer – especially near the vessel walls.

A tripod frame is used for this operation (Fig. 2). It brings the lysimeter vessel into a vertical position and stabilises it during the cutting process to prevent the axis deflection. At the bottom of vessel a rotary cutting tool is attached. Its function is to carve out the soil and prepare the space for the vessel. It rotates around the rim of vessel to leave excess of 2-4 cm. Own weight of vessel pushes it down to penetrate into carved soil with no extra pressure on soil core edges and no risk that there is a space between the monolith and vessel wall. Once the depth of soil monolith is reached, it is cut by the cutting plate and hydraulic pushing device. Then lysimeter vessel including the soil monolith is lifted out of the excavation pit for the next processing and instrumentation (Fig. 3).

Fig. 2. Lysimeter soil retriever

Fig. 3. Soil monolith with lysimeter vessel

4. Data acquisition and processing

Lysimeter station generates a large dataset continuously which requires well developed information technology infrastructure to process it. Data collection can be set up at various time interval. It depends on the research aim. In hydrology research the time interval can be very short (1-5 minutes) but in field of agriculture it can be longer. Raw data are collected into data-loggers and some of them are processed there. The main data-logger is responsible for the dataset transmission into central server. Next data flow can be managed according to the special requirements of researchers. Lysimeter stations are installed very often in open field or terrain conditions with no electricity and internet connection. So that the energy supply can be realized either by solar panels or by electrical network [5]. Data transmission can be also managed in two different ways. Stabile internet connection can be replaced by radio or GSM signal. Fig. 4 interprets the scheme of data flow in lysimeter station in Borovce in Slovakia. Data is stored in the main database on central server. Using the Internet network, data is sent to a user´s computer and they are available anytime in the form of database files, but also visualized in the form of graphs. At the same time the data is controlled by the staff of developer. Via remote access the staff is able to adjust the system configuration or to carry out the necessary corrections of device set up, to eliminate a technical failure or software conflicts [8].

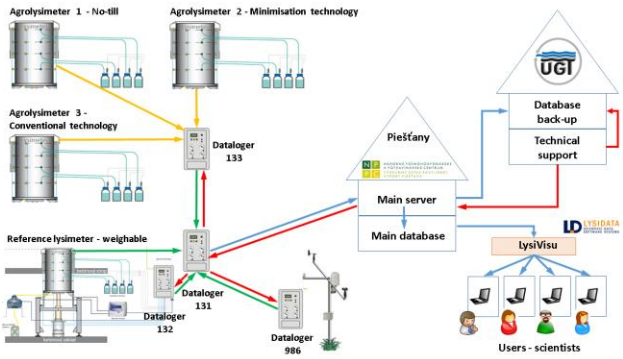

Fig. 4. Data flow in lysimeter station (Borovce, Slovakia)

Depending on the size of complete primary dataset, data are processed by Lysidata or Svadss software. These two software are developed to data visualisation. They allow to create graphs for quick and better overview of investigated situations or target sensors. Visualisation is a tool for detailed image of various parameters of ecosystem to better interpretation of relationships amongst them. Time period and selection of sensors is the basic function. User can adjust the range of parameters, colour or type of graphs. Then, it is possible to export chosen data into another software for the next processing (e.g. MS Office - Excel). Access to data is treated by administrator based on the user access rights. Standard part of software is the facility control system and error notification in case of some technical problems [11].

Fig. 5 shows an example of data visualisation. Precipitation, solar radiation and monolith weight can be mentioned as some of the basic parameters, which can contribute to evapotranspiration explanation and water balance respectively. Their progress in chosen time period is depicted in Fig. 5. Significant response of monolith weight (green line) regarding the solar radiation (red line) and precipitation (blue line) is visible on graph [3ret].

In recent years the new applications have been developed and introduced to the practice. They allow data monitoring and data visualisation via remote access by smartphones and similar devices.

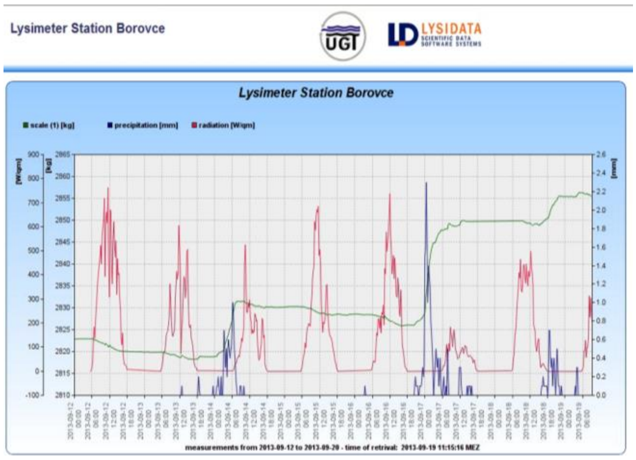

Fig. 5. An example of data visualisation by Lysidata software

5. Lysimeter applications.

If there is a lysimeter well equipped by mentioned technologies, one can think about the research aims. Based on them, the suitable measuring devices are chosen and installed on the basic lysimeter vessel to get the required data. Nowadays, following research areas use the lysimeters:

- Agriculture. Impact of soil management and crops cultivation on soil quality and water balance can be investigated. Irrigation management as well as the fertilisation and doses of chemicals can be well optimised by lysimeter data.

- Environment. Nowadays, the big attention is paid to issues of air and soil contamination and their influence on the quality of environment. Especially the interaction of these two contamination vectors with water and consequent contaminant percolation into the ground water as well as uptake by plants can be monitored by lysimeters in natural conditions. Concurrently it is possible to study these processes with regard to the weather conditions. It was found out that the modelling of soil contaminants transport in laboratory conditions has shown significant differences in comparison to the fate of contaminants in real natural conditions. From this point of view the lysimeter has important status in science [7].
- Hydrology. Determination of evapotranspiration, evaporation and water distribution by lysimeters in different soil types or ecosystems is performed exactly. Influence of weather on these processes is automatically included. Modelling of influence of groundwater table on capillary rise is also possible. Monitoring of soil water movement in saturated and unsaturated zone can be studied. It is often said, that these research tasks can be mathematically modeled and calculated. But it is often forgotten, that every mathematical model is as exact as its input data are. The results are reliable only if they are validated by experimental measurements in natural conditions. Lysimeter can be directly used for the results validation.
- Climate change. Scientists and public are involved into discussions focused on climate change and its impact on future life quality via agricultural productivity and water balance in ecosystems. Lysimeter in relation to the meteorological data provides the complex image of current state of ecosystem and it is suitable for long-term observations and data evaluation.

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Сучасні лізиметричні об'єкти у зв'язку з метеорологічними станціями дозволяють здійснювати контроль та оцінку екосистемно пов'язаних основних компонентів довкілля, таких як вода, повітря, ґрунт і рослинність. Вода є найбільш важливим компонентом екосистеми та елементом, який поєднує всі інші компоненти. Тому необхідне знання щодо основного розподілу і водного балансу у різних компонентах довкілля, щоб інтерпретувати процеси в природі. Кількість опадів, що є основним джерелом життєво важливих процесів у ґрунті, формується в повітрі. Кількість опадів, що потрапляє в ґрунт і ґрунтові води, залежить від погодних умов. Первинний розподіл дощової води ділиться між інфільтрацією, поверхневим стоком, транспірацією та евапотранспірацією. Кількість води, що проникає в ґрунт, а потім випаровується за рахунок сонячної активності або діяльності рослин, можна визначити, у першу чергу, шляхом моніторингу змін у вазі. Для цього моніторингу ми використовуємо вагомий лізиметр. Це обладнання розміром з моноліт, площа поверхні якого 1 м2 і глибина 1,5 м, здатне стежити в онлайн режимі за оновленням ваги маси в 2 тони з точністю до 100 г. Коли ми додаємо до кількісної оцінки фільтрат нижнього шару, ми отримуємо повноцінний облік опадів в довкіллі щодо окремих компонентів. Отримані дані можна інтерпретувати з точки зору потреб гідрології, сільського господарства, довкілля та відповідно до цілей і завдань, для яких ми хочемо їх використовувати.

Ключові слова: гідрологія, лізиметричне дослідження, комплексне вивчення екосистем, розподіл і баланс води, сучасні польові технології в екології, сільське господарство, моніторинг навколишнього середовища.

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Современные лизиметрические объекты в комплексе с метеорологическими станциями позволяют осуществлять контроль и оценку основных компонентов окружающей среды, таких как вода, воздух, почва и растительность. Вода является наиболее важным элементом экосистемы и элементом, который соединяет все другие компоненты. Поэтому, мы должны знать основное распределение и водный баланс в различных компонентах окружающей среды, чтобы уметь интерпретировать любой процесс в природе. Количество осадков, которое является основным источником жизненно важных процессов в почве, формируется в воздухе. Количество осадков, которое попадает в почву и грунтовые воды, зависит от погодных условий. Первичное распределение дождевой воды делится между инфильтрацией, поверхностным стоком, транспирацией и эвапотранспирацией. Количество воды, проникающее в почву, а потом испаряющее за счет солнечной активности или деятельности растений можно определить, в первую очередь, путем мониторинга изменений в весе. Для этого мониторинга мы используем весомый лизиметр. Это оборудование размером с монолит, площадь поверхности которого 1 м2 и глубина 1,5 м, способно следить в онлайн режиме за обновлением массы весом в 2 тонны с точностью до 100 г. Когда мы добавляем к количественной оценке фильтрат нижнего слоя, мы получаем полноценный учет осадков в то же время в среде с отдельными компонентами. Полученные данные можно интерпретировать в терминах с точки зрения потребностей гидрологии, сельского хозяйства, окружающей среды и в соответствии с целями и задачами, для которых мы хотим их использовать.

Ключевые слова: гидрология, лизиметрические исследования, комплексное изучение экосистем, распределение и баланс воды, современные полевые технологии в экологии, сельское хозяйство, мониторинг окружающей среды.

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