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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том I  Ландшафты в XXI веке: анализ состояния, основные процессы и концепции исследований

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Chapter I/63: VIRTUAL LYSIMETER FOR UNDERSTANDING AND MONITORING DEEP SEEPAGE PROCESSES

 Глава I/63: Виртуальные лизиметры для понимания и мониторинга процессов глубокого просачивания

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ABSTRACT. Lysimeters are the main devices for monitoring and quantifying soil water and solute balances and transport processes. However, certain characteristics of lysimeters, high costs and limited flexibility act as restricting arguments. There is a lack of effective and reliable methods for quantifying deep seepage under undisturbed soil and for managing conditions in the field. Soil hydrology measurements, so called virtual lysimeters provide an alternative way for quantifying deep seepage and solute leaching in situ. The method presented here offers simple handling, flexibility, and costs less than lysimeters. The required soil hydraulic properties are only derived from tension and water content field recordings below the flux plane. After calibration of the derived hydraulic conductivity function, no further information about soil properties, weather, management and land use data is required, nor is any other data. Since 1994, the method has been successfully applied at many sites in northeast Germany. A comparison between lysimeter discharge measurements and discharge calculations has confirmed the validity of this method.

Резюме. Лизиметры - это основные устройства для мониторинга и количественного определения балансовых и транспортных процессов в почве и растворенных веществах. Однако некоторые характеристики лизиметров, высокая стоимость и ограниченная гибкость действуют как ограничивающие аргументы. Отсутствуют эффективные и надежные методы количественного определения глубинной фильтрации в ненарушенном грунте и для управления условиями на местах. Гидрологические измерения почвы, так называемые виртуальные лизиметры, обеспечивают альтернативный способ количественного определения глубинной фильтрации и выщелачивания растворенного вещества. Представленный здесь метод предлагает простое управление, гибкость и затраты меньше, чем при обычных лизиметрических исследованиях. Необходимые гидравлические свойства грунта производятся только из полей напряженности и содержания воды ниже плоскости потока. После калибровки производной функции гидравлической проводимости дополнительная информация о свойствах почвы, данных о погоде, управлении и землепользовании, а также некоторых других не требуется. С 1994 года этот метод успешно применяется на многих объектах в северо-восточной Германии. Сравнение между измерением разряда лизиметра и расчетами разряда подтвердило справедливость этого метода.

KEYWORDS: soil hydrological measurement, deep seepage, solute leaching, virtual lysimeter.

Ключевые слова: почвенные гидрологические измерения, глубокое просачивание, выщелачивание растворенного вещества, виртуальный лизиметр

INTRODUCTION

Quantifying groundwater recharge to aquifers is necessary for tackling numerous economic and environmental problems such as providing non-polluted water for different uses, protecting drinking water and determining safe yields from aquifers. For centuries, lysimeters have been the main devices for monitoring and quantifying soil water and solute balances and transport processes. Depending on the instrument’s construction and management, results are influenced by special lysimeter effects [1]. Besides this weakness, lysimeters are expensive and inflexible. There is a lack of effective and reliable methods for quantifying deep seepage under undisturbed soil and managing conditions in the field. Soil hydrology measurements (virtual lysimeter) provide an alternative way of analysing the soil water and matter status in situ under undisturbed soil conditions. Compared with lysimeters, these methods are less expensive and
more flexible. However, taking measurements at various sites and with many sensors across the whole profile is also expensive and is not a feasible solution. Following a simple soil hydrological field method for quantifying deep seepage and solute leaching is presented and its validity has been tested in comparison with lysimeter measurements.

**AIM OF THE METHOD**
The soil hydrological field method aims to quantify deep seepage and solute leaching under natural soil and land use conditions in a simple way. In this paper we explain the novel method, present a comparison with lysimeter results to show the validity of the method.

**PRINCIPLE AND PROCEDURE**

**Principle.** Below the zero flux plane, water flow is driven by gravity only (Fig. 1).

All changes of water content or tension are induced by changing seepage conditions. Transformation of soil water content into flux (seepage flow rate \(v\)) can be undertaken using the Darcy Buckingham equation (\(v = K(\Theta) \cdot i\), Eq. 1) containing a non-linear scaling factor, where the hydraulic conductivity function \(K(\Theta)\) is dependent on water content \(\Theta\), and the hydraulic gradient \(i\) is the driving force. “Steady-state” conditions are assumed at daily intervals and the unit hydraulic gradient is considered to be valid [2]. This method is feasible on soils without ground water influence. Daily deep seepage rates \(v\) are calculated based on water content measurements below the zero flux plane, and an unsaturated hydraulic conductivity function \(K(\Theta)\) calibrated to the water balance. Further information about soil properties, land management, weather data and other data is not necessary. Prerequisites are high precision and temporally stable tensiometers and TDR probes with no drift or temperature influence and temporally constant flow pathways.

**Procedure.** Water content and tensions are recorded with a high temporal resolution below the zero flux plane. The recommended measurement depth at arable sites in a humid climate is 3 m, and at forest sites, 5 m. From these data a field water retention function is derived and fitted (Eq. 2, [3]).

\[
\Theta(\Psi) = \Theta_r + \frac{\Theta_s - \Theta_r}{1 + (\alpha \Psi)^n}
\]  
(2)
with
\[ \Theta_s \quad \text{saturated water content} \]
\[ \Theta_r \quad \text{residual water content} \]
\[ \alpha, n, m \quad (m=1-1/n) \quad \text{parameters} \]
and the relative hydraulic conductivity function \( K_r(\Psi) \) is predicted Eq. (3) [4].

\[
\frac{K(\Psi)}{K_s} = K_r(\Psi) = \left[ 1 - (\alpha \Psi)^{\alpha - 1} \left[ 1 + (\alpha \Psi)^{\alpha - 1} \right]^{-\frac{1}{\alpha}} \right] \left[ 1 + (\alpha \Psi)^{\alpha - 1} \right]^{-\frac{m}{2}}
\]  

(3)

with
\[ K(\Psi) \quad \text{hydraulic conductivity dependent on tension} \]
\[ K_s \quad \text{saturated hydraulic conductivity} \]
\[ K_r(\Psi) \quad \text{relative hydraulic conductivity} \]

Substituting \( \Psi \) in Eq. 3 by Eq. 4 gives the hydraulic conductivity as a function of water content. The use of \( K(\Theta) \) minimises hysteresis effects. Any extrapolation of \( K(\Theta) \) beyond field recordings is not permitted.

\[
h = f(\Theta) = \left[ \left( \frac{\Theta - \Theta_r}{\Theta - \Theta_s} \right)^{\frac{1}{\alpha}} - 1 \right]^{\frac{m}{\alpha}}
\]  

(4)

In the next step, fictitious seepage rates \( v_r \) are calculated (Eq. 1) based on the recorded water content values \( (\Theta) \) and the relative hydraulic conductivity function \( K_r(\Theta) \). A unit gradient \( i=1 \) is assumed. This assumption has been validated [2], and prompts only small uncertainties. To provide reliable seepage rates \( V_c \), the relative hydraulic conductivity function has to be converted to a reliable level. First, the water balance (Eq. 5) is determined for a frost-free autumn/winter period. Precipitation \( (P) \) should be measured at the site of the experiment. The soil water storage difference \( (\Delta \Theta) \) is derived from water content measurements in the profile from the beginning and the end of the calibration period. The ratio \( V_c/V_f \) reveals \( M \) as the matching factor (Eq. 6) for transforming the \( K_r(\Theta) \) function to a reliable level \( (K(\Theta)) \). Finally, Eq. 5 is used for calculating reliable daily seepage rates. The term \( f(\Theta) \) in Eq. 7 substitutes \( (\Psi) \) according to Eq. 4.

\[
V_c = P - ET + \Delta \Theta
\]

(5)

\[
M = \frac{V_c}{V_f}
\]

(6)

\[
v = M \cdot K_r(\Theta) = \frac{V_c}{V_f} \left[ 1 - (\alpha \cdot f(\Theta))^{\alpha - 1} \left[ 1 + (\alpha \cdot f(\Theta))^{\alpha - 1} \right]^{-\frac{1}{\alpha}} \right] \left[ 1 + (\alpha \cdot f(\Theta))^{\alpha - 1} \right]^{-\frac{m}{2}}
\]  

(7)

RESULTS
The soil hydrological method was successfully applied at more than 40 plots in North-East Germany [5]. Figure 2 exemplarily shows a measurement plot at the Müncheberg experimental field and the kind of installation. The validation of the method was carried out in comparison with lysimeter discharge measurements. Data from the lysimeter stations Dedelow [6] and Wagna, Steiermark, Austria, [7], [8] were used.


Some soil physical properties and the stratification are collected in Table 1.
Table 1 - Stratification and soil physical properties of the lysimeters

<table>
<thead>
<tr>
<th>Site</th>
<th>Horizon</th>
<th>Depth cm</th>
<th>OMC %</th>
<th>ρ g cm⁻³</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Sand %</th>
<th>Gravel %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedelow</td>
<td>Ap</td>
<td>0 – 35</td>
<td>1.1</td>
<td>1.52</td>
<td>4</td>
<td>24</td>
<td>71</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Bv</td>
<td>35 – 115</td>
<td>0.1</td>
<td>1.63</td>
<td>9</td>
<td>28</td>
<td>62</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>115 – 200</td>
<td>0.1</td>
<td>1.65</td>
<td>1</td>
<td>4</td>
<td>93</td>
<td>2</td>
</tr>
<tr>
<td>Wagna.</td>
<td>A</td>
<td>0 - 30</td>
<td>2.2</td>
<td>1.53</td>
<td>19</td>
<td>34</td>
<td>45</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>30 - 110</td>
<td>1.3</td>
<td>1.55</td>
<td>14</td>
<td>28</td>
<td>57</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>110 - 190</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td>30</td>
<td>69</td>
<td></td>
</tr>
</tbody>
</table>

OMC: organic matter content, ρ: dry bulk density of the soil, clay: < 0.002mm, silt: 0.2 - 0.63mm, sand: 0.63 - 2mm; gravel: 2 - 63mm

The lysimeters were equipped with TDR instruments and tensiometers comparable to the field measurements. The measured daily discharge rate was compared with the calculations based on the water content and tension measurements. The Willmott Index of Agreement Eq. 8 [9] was used for the evaluation of the comparison of the measured and calculated discharge rates. The index varies between 0 (poor agreement) and 1 (perfect agreement).

\[ d = 1 - \frac{\sum (O_i - P_i)^2}{\sum \left( |P_i - O_m| + |O_i - O_m| \right)^2} \]  

(8)

O_i - observed values, P_i - predicted values, O_m - mean observed value

Figure 2 - Installation of a soil hydrological measurement (MP) plot at the Müncheberg experimental field.
The comparison (Fig. 3) of the measured with the calculated discharge rates performed a good agreement for the lysimeter in Dedelow \( (d = 0.97) \) and Wagna \( (BIO- d = 0.91) \). In conclusion, the proposed method for quantifying deep seepage rates based on soil hydrological measurements performed well. This agrees with simulation findings by [10].

CONCLUSIONS
1. The presented method for estimating deep seepage rates and solute leaching on the basis of soil hydrological measurements in the field was successfully applied and the suitability was tested with lysimeter experiments. The method is simple to handle, is flexible and is less expensive than lysimeters.
2. The method is suitable for sites without ground water and no preferential flow.
3. The method has potential for application and adaption to soils in Russia and Central Asia.

REFERENCES
Chapter I/64: IMPACT OF LAND USE ON DEEP SEEPA GE DYNAMICS IN NORTH EAST GERMANY
Глава I/64: Влияние землепользования на динамику глубокой перколяции воды в Северо-Восточной Германии

Uwe Schindler*; Lothar Mueller

ABSTRACT. Starting in 1993, continuous measurements of soil water tension and water content down to a depth of 5 m at 36 plots situated at diverse soils under different land use (arable land, forest, grass fallow) in North East Germany. At arable sites, the main period of deep seepage occurred between February and April. With 175 mm a\(^{-1}\), the mean annual deep seepage rate under arable land was highest at sandy soils. On loamy soils, the mean seepage rate amounting to 122 mm a\(^{-1}\) appeared significantly less. Smallest seepage rates, however, were determined for forested plots (pine 15 mm a\(^{-1}\), beech 18 mm a\(^{-1}\)). Differences were significant as compared to arable land at sandy and loamy soils and grass fallow. It is concluded that deep seepage and groundwater recharge under forest will tend to wane at annual precipitation rates of < 550 mm a\(^{-1}\). This should be taken into account in decision making on land use planning and conversion of arable areas to forestry in regions characterised by negative values of the climatic water balance.

KEYWORDS: soil hydrological measurement, deep seepage, solute leaching, virtual lysimeter.

KEYWORDS: land use, cropland, grassland, forest, deep seepage, measurement, virtual lysimeters, Germany

Ключевые слова: землепользование, пахотные земли, луга, лес, глубокая перколяция, измерение, виртуальные лизиметры, Германия