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# Are solute concentrations measured in leachate tank and in by-pass collection flask of TERENO SoilCan lysimeters comparable?

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## Zusammenfassung

Bei Lysimetern, die als Ackerland bzw. ungedüngtes Grünland genutzt werden und die über eine kontrollierte untere Randbedingung verfügen, wurden die Stoff-Konzentrationen in Bypass-Flaschen und in Sickerwassersammelgefäßen verglichen. Während die Bypass-Flaschen ausschließlich bei Entwässerung der Lysimetergefäße gefüllt werden, wird Wasser im Bewässerungsfall aus den Sickerwassersammelgefäßen entnommen und in die Lysimetergefäße zurück gepumpt. Die in den Bypass-Flaschen und in den Sickerwassersammelgefäßen gemessenen Konzentrationen unterschieden sich deutlich (verschiedene Elementmuster). Aufgrund von Verdünnungseffekten (Nachfüllen von Wasser) waren die in den Sickerwassersammelgefäßen gemessenen Konzentrationen tendenziell niedriger. Aussagen zum sickerwassergebundenen Stoffaustrag sollten bei Lysimetern mit kontrollierter unterer Randbedingung nur anhand der in Bypass-Flaschen gemessenen Stoff-Konzentrationen abgeleitet werden.

## Summary

For lysimeters used as arable land or unimproved grassland and having a controlled lower boundary condition, the solute concentrations in by-pass and leachate tanks were compared. While the by-pass bottles are only filled with lysimeter seepage, water is taken during watering periods from the leachate collection tank and pumped back into the lysimeter vessels. The solute concentrations measured in the by-pass bottles and in the leachate collection tanks differed significantly (different element patterns). Due to dilution effects (supply of additional water), the concentrations measured in the leachate collection tanks tended to be lower. Statements on seepage-related solute discharge should only be derived from lysimeters with controlled lower boundary based on solute concentrations measured in by-pass bottles.

*Keywords:* Lysimeter technique, seepage sampling, solute concentration, seepage tank, by-pass flasks

## Introduction

Conventional gravitation lysimeters are regarded to be a suitable tool for studying the water and solute balance of soils (Allen et al. 2011, Weihermüller et al. 2007). By seepage water sampling and the subsequent chemical analysis, solute fluxes with the leachate stream can be exactly quantified. Thereby, conventional gravitation lysimeters allow the quantification of seepage-related solute fluxes, whose knowledge is important for compliance with environmental quality objectives. Lysimeter vessels were frequently filled with soil monoliths. These monoliths were often taken away from their originating sites. At conventional gravitation lysimeters seepage occurs when the soil at lower boundary is saturated (seepage-face boundary condition). Upwards directed fluxes were not adequately considered by these lysimeters. Disconnecting the capillary connection with deeper soil affects the drainage and prevents capillary rise and may lead to a bias in the drainage and in the solute transport processes so that lysimeter observations are not directly transferable to field scale conditions (Groh et al. 2016). A controlled lower boundary was developed which overcomes the disadvantages of conventional lysimeters (Fank and Unold 2007), so that the water balance and moisture profiles in the lysimeter correspond closely to those that would prevail in the undisturbed soil profile. The controlled lower boundary was operated by drainage or injection of seepage at the bottom of the lysimeter vessel by a system consisting of bi-directional pumps, tubes and a suction rake.

The concentration of typical ions and compounds analyzed in leachate tank and in the by-pass collection flasks was statistically compared to estimate possible impacts from lower boundary control on solute concentrations.

## Material and methods

As part of the TERENO SoilCan lysimeter network, lysimeter stations were built in 2010 at the Sauerbach site (SB) and at the Schäfertal site (ST), both in the Bode catchment, Germany. Each lysimeter station consists of six monolithically filled lysimeter vessels. Both lysimeter stations differ in land management, arable land (SB) versus unimproved grassland (ST). All lysimeters have a controlled lower boundary in which the matrix potential is controlled by using bi-directional pumps according to the comparison of matrix potential (actual value) measured in the lysimeter and the matrix potentials (target value) determined outside by 3 field tensiometers. If the soil moisture content inside the lysimeter vessel is increased compared to the field site, the lysimeter have to be drained. In that case, water is pumped out of the lysimeter vessel via the suction rake installed at

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*Table 1.* **Differences between solute concentrations in by-pass flasks and leachate tank of the sites Sauerbach (SB) and Schäfertal (ST) (+ significant difference, - no significant differences, probability value < 0.05).**

| Lys.- | Analysis criteria | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| site | $NO_3$ | $NH_4$ | $NO_2$ | K | Na | Ca | Mg | EC | pH | $SO_4$ | Cl | TP | DOC |
| SB_1 | + | - | - | + | - | + | + | + | - | - | - | - | - |
| SB_2 | + | - | - | + | + | + | + | + | + | - | + | - | - |
| SB_3 | + | - | + | + | + | + | + | + | + | - | + | - | + |
| SB_4 | + | - | - | - | - | + | + | + | + | - | + | - | - |
| SB_5 | - | - | - | + | - | + | + | + | + | - | - | - | - |
| SB_6 | - | - | - | - | - | - | + | + | + | - | - | - | - |
| ST_1 | - | - | - | - | - | - | - | - | - | + | - | - | + |
| ST_2 | - | - | - | - | - | - | - | - | - | - | - | - | + |
| ST_3 | - | - | - | - | - | + | - | - | - | - | - | - | + |
| ST_4 | - | - | - | - | - | - | - | - | - | - | - | - | + |
| ST_5 | - | - | - | - | - | - | - | - | - | + | - | - | + |
| ST_6 | - | - | + | - | - | - | - | - | - | - | - | - | + |

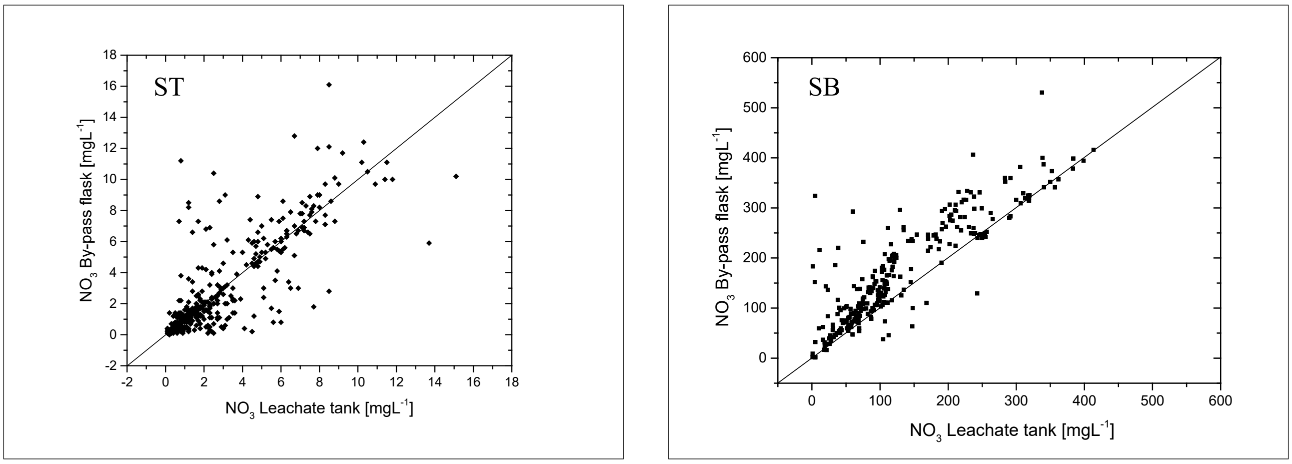


*Figure 1.* **Scatter plot of nitrate concentrations analyzed in leachate tanks and by-pass flasks of site ST and SB.**

the bottom of the lysimeter vessel into the leachate tank. Simultaneously, a defined sub-sample is taken from the leachate stream via a by-pass pump and collected in a separate collecting flask. In the watering case (soil moisture content at the field site is increased compared to the conditions inside the lysimeter vessel) already collected seepage water is taken from the leachate tank and pumped back into the lysimeter. In the climatic conditions of North-East Germany with an average annual precipitation of about 650 mm the climatic water balance is stressed. Seepage formation disappeared in late summer and the water demand by plant roots and evapotranspiration is satisfied by capillary rise from deeper soil horizons. In these critical phases the water volume available in the leachate tank was sometimes completely used up for sub-surface irrigation at the lower boundary condition, so that additional water has to be added here (accumulated lysimeter leachates or drinking water). This procedure resulted in a substantial mixture of water used for the watering of the lower boundary condition of the lysimeter vessel.

If present, water samples were collected every 2 weeks. They were transported to the UFZ lysimeter facility in Falkenberg, Saxony-Anhalt, Germany and analyzed in the lab for nitrate ($NO_3$), ammonium ($NH_4$), nitrite ($NO_2$), sulfate ($SO_4$), potassium (K), calcium (Ca), sodium (Na), chloride (Cl), total phosphorus (TP), dissolved organic carbon (DOC), electrical conductivity (EC) and pH.

Descriptive statistical methods with linear regression function were applied for data assessment and performed using the software package ORIGIN (OriginLab Corporation, Northampton, USA). Since measured values were not normally distributed, the Kruskal–Wallis test (One-way ANOVA on ranks) as a non-parametric method was used for testing whether lysimeter data originate from the same distribution. A cluster analysis was applied to discover similarity structures within the whole data set of site SB.

## Results and discussion

The agriculturally managed and fertilized lysimeters at SB showed numerous statistical significant differences in solute concentration between leachate tank and by-pass flasks (*Table1)*. At the ST site, only DOC showed in contrast to SB site almost exclusively significant differences in solute concentrations in leachate tank and by-pass flasks.

The different pattern of solute concentration in by-pass flasks and leachate tank was caused by the different agricultural management of both sites. The concentration pattern in by-pass flasks of site SB was predominately influenced by ions added with mineral fertilization. These effects were not observed by means of the concentrations patterns at the unimproved grassland site ST.

Solute concentrations in leachate tank tended to be decreased compared to by-pass flasks (*Figure 1*) at the SB site due

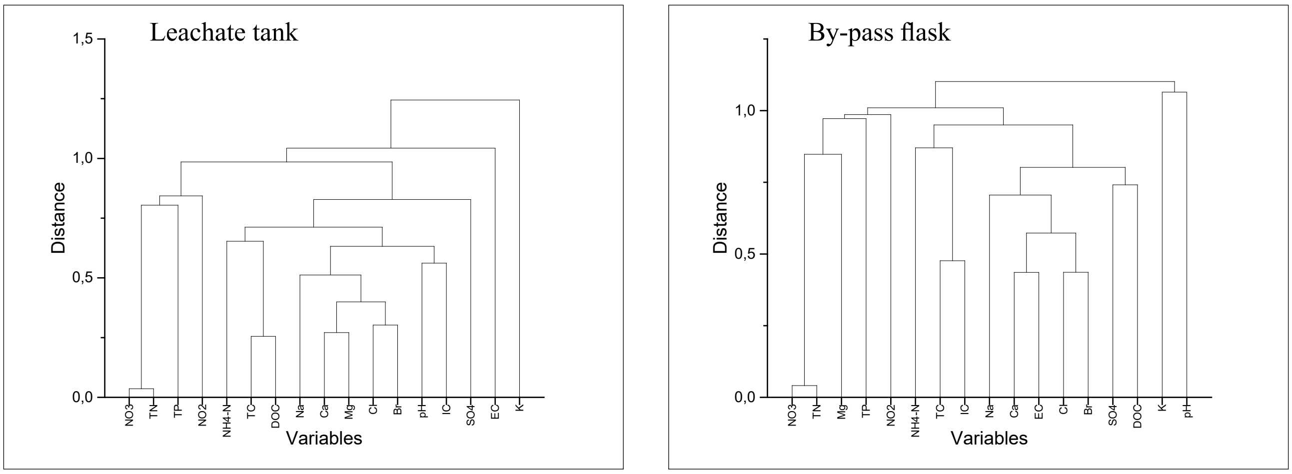


*Figure 2.* **Cluster analyses (dendrogram) of solute concentration in leachate tank and by-pass flasks of site SB.**

to a dilution effect (feeding of potable water for watering at the lower boundary). Contrary, this effect couldn't be observed at site ST. The measured nitrate concentrations were very low in leachate tank and by-pass flask at this site. The DOC concentrations in the by-pass flasks were significantly higher than the values measured in the leachate tanks.

The site SB was chosen for an advanced statistical data analysis due to the fact, that significant differences between solute concentrations in leachate tanks and by-pass flasks were predominately proven for this site. As result of the statistical analysis (cluster analysis) different patterns of solute concentration in leachate tanks and by-pass flasks became apparent (*Figure 2*). Solute concentrations in by-pass flasks were obviously dominated by leaching processes. By adding tap water and or stored seepage, solute concentrations in leachate tanks are more influenced by dilution effects.

## Conclusions

The study showed a clear influence of the agricultural land management on measured solute concentrations in the by-pass flask. Bi-directional pumping and adding of supplementary water resulted in dilution effects in leachate tanks. Due to different solute concentration patterns both sampling locations differ significantly. Statements about solute leaching with seepage fluxes can only be deduced from the leachate collected in by-pass flasks. Hence, water from leachate tank should not be analyzed, given that the effect of adding potable water cannot be quantified reliably.

## Literature

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