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# SOIL WATER MOBILITY: AN ALTERNATIVE LABORATORY METHOD FOR ITS DETERMINATION

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***Abstract***

*A new laboratory method was proposed to establish an easily performed standard for the determination of mobile soil water close to real conditions during the infiltration and redistribution of water in a soil. It consisted of applying a water volume with a tracer ion on top of an undisturbed ring sample on a pressure plate under a known suction or pressure head. Afterwards, soil water mobility was determined by analyzing the tracer-ion concentration in the soil sample. Soil water mobility showed to be a function of the applied water volume. No relation between soil water mobility and applied pressure head could be established with data from the present experiment. A simple one- or two-parameter equation can be fitted to the experimental data to parameterize soil water mobility as a function of applied solute volumes. Sandy soils showed higher mobility than loamy soils at low values of applied solute volumes, and both sandy and loamy soils showed an almost complete mobility at high applied solute volumes.*

***Keywords****: laboratory method, mobile-immobile water, pressure head, soil texture.*

## INTRODUCTION

Solute movement models are essential for estimating impacts of waste disposal, surface mining, and pesticide application and for predicting fertilizer efficiency and environmental impacts.

In order to extend predictions of hydraulic and preferential flow properties in modelling of solute transport processes, models usually distinguish a mobile and an immobile water fraction (Gaudet et al., 1977). Mobile is located inside the mobile pore domain (usually large and inter-aggregate pores) and immobile water is mostly located inside aggregates (small and intra-aggregate pores). Transfer by diffusion between mobile and immobile domains is proportional to the concentration difference between the mobile and immobile liquids.

A hydrological sulphur model (HYSUMO) was developed and simulates the S cycle in the soil. The soil water fractions, and plant uptake, including the mobile and immobile soil water fractions and the importance of this concept for S balance modelling have been discussed by Bloem et al., 2005 that showed the immobile soil water fraction affected leaching, nutrient availability, and groundwater pollution, storing a non-negligible part of nutrients and therefore contributing to plant nutrition.

Equipment, tracers, and the necessary equations support for deterministic or stochastic assessment of soil water mobility have been developed for both field and laboratory conditions (Clothier et al., 1992; Jaynes et al., 1995).

To improve and validate a model like HYSUMO it is necessary to develop a non-steady state method that allows the quantification of the mobile and immobile soil water fractions under non-equilibrium conditions. In this paper a laboratory method for this determination is described.

## MATERIALS AND METHODS

Undisturbed soils samples (0.04m high; 0.056m diameter) were collected from four German soils, differing in texture, physical properties and groundwater conditions, at a depth between 0.05 and 0.15m (Table 1).

Table1. Physical characteristics of the to soil and groundwater conditions of the investigated four soils

| Soil | Bulk density | Clay | Silt | Sand | GW deep |
|---|---|---|---|---|---|
| | kg m$^{-3}$ | ----------------g kg $^{-1}$--------------- | | | m |
| Loam 1 | 1492 | 260 | 470 | 270 | 2.3 |
| Loam 2 | 1480 | 310 | 510 | 180 | 1.5 |
| Sand 1 | 1426 | 100 | 80 | 820 | 5.5 |
| Sand 2 | 1140 | 120 | 120 | 760 | 0.8 |

From each soil, 45 undisturbed samples were used to perform the hydraulic pulse experiment and 3 to determine soil water retention at selected pressure heads (-5, -10, -20, -40, -60, and -100 cm). One of the retention samples of the loam 1 soil showed very different results compared to the others samples and was thus not consideredin subsequent analyses. For hydraulic characterization, retention data were fitted to the van Genuchten (1980) equation:

$$\Theta = [1 + |\alpha h|^{n}]^{(1-n)/n} \quad (1)$$

with:

$$\Theta = (\theta - \theta_r)/( \theta_s - \theta_r) \quad (2)$$

where $\Theta$ is soil water fraction, $\theta$, $\theta_s$ and $\theta_r$ are water content, saturated water content and residual water content (m m$^{-3}$), respectively, h is the pressure head (cm), $\alpha$ (cm$^{-1}$) and n are empirical parameters.

To allow calculating the soil water mobility, a non-reacting, non-absorbing and easy to detect ion was used as a tracer. Chloride was chosen in this study and to assure that soil samples were totally equilibrated to a known concentration ($C_0$) of the ion, initial tests were performed and showed that it took a considerable time for soil samples to equilibrate by diffusion. Therefore, samples were left in a chloride solution for 28 days and ceramic plates were equilibrated to the same concentration for 24 h. Samples were put on the suction plate to equilibrate hydraulically to a pressure head (h) equal to -5, -10, -20, -40 and -60 cm. Filter paper was put on top of the samples and different volumes of solution (0.5, 1.0 and 2.0 times of the mean sample pore volume) with a chloride concentration $C_1$ was applied on that. Sample and porous plate were then covered to minimize evaporation.

Twenty four hours after $C_1$ application samples were analysed. On third of the sample was used to determine the soil water content and the remaining part to measure the chloride concentration [Cl$^-$] in the soil solution. For this, the soil samples were shaken with 50 mL deionized water for 24 h. The suspension was then filtered through Schleicher & Schuell No 593 filter paper and analyzed with a Cl specific electrode (S7, Mettler Toledo), from which [Cl$^-$] in the soil solution ($C_s$, mol L$^{-1}$) could be recalculated.

Supposing chloride diffusion to be negligible, the values of $C_0$, $C_1$ and $C_s$ allow to estimate the mobile and immobile soil water fraction relative to the soil water content ($\Theta_m$ and $\Theta_{im}$ respectively, in m$^3$ m$^{-3}$) (Clothier et al., 1995):

$$\Theta_m = (C_0 - C_s)/ (C_0 - C_1) \quad (3)$$

$$\Theta_{im} = (C_s - C_1)/ (C_0 - C_1) \quad (4)$$

Values for mobile and immobile water contents were thus obtained as a function of pressure head and applied pulse volume.

## RESULTS AND DISCUSSIONS

The observed soil water retention curves are shown in Figure 1. The sand soils especially sand 1 showed a high porosity in the lower suction ranges. Sand 1 released more than half of its water at a pressure head around -50 cm.

The loamy soils showed little variation in water content up to -100 cm. Thus, higher water mobility as well as greater differences between the investigated pressure heads could be expected for the sandy soils.

Mathematical analysis of Eq. showed that a high value of $\alpha$ was associated to an inflection point (*i.e.*, a maximum porosity) at low values of h, corresponding to a high macroporosity. However, values of n close to 1 led to a low inclination at the inflection point, smoothing the porosity distribution and making its maximum less significant. This was the case for loam 2. In general, high values of $\alpha$ are expected to be associated to higher water mobility.

The experimentally determined mobile fractions are shown in Figure 2.

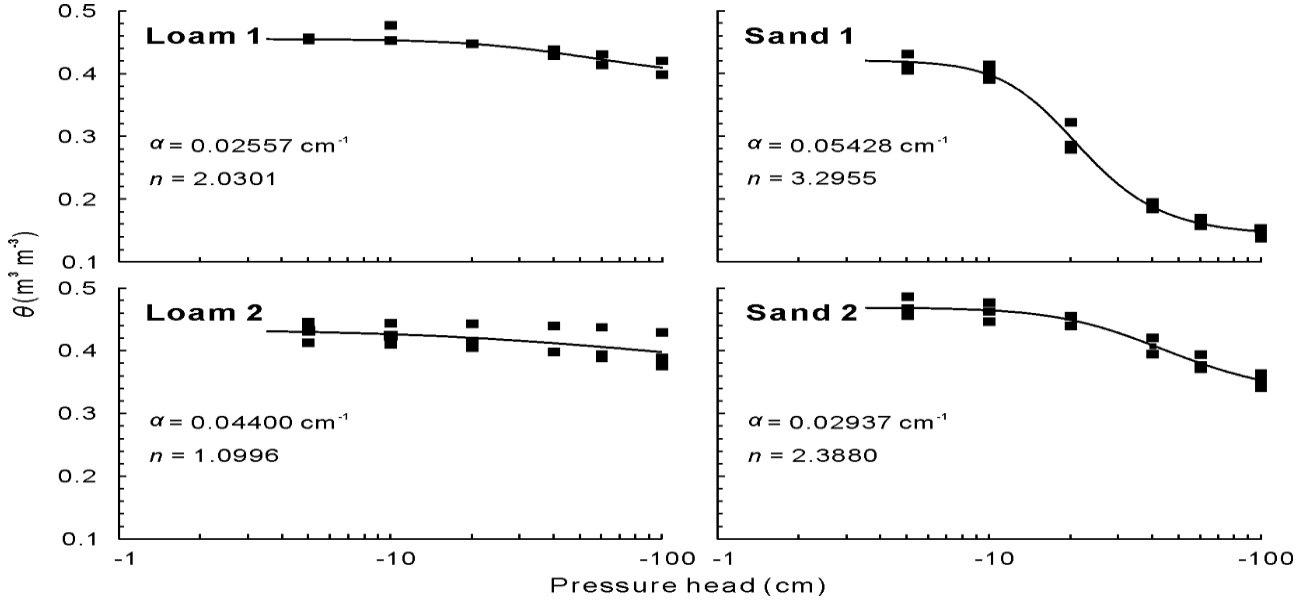

Figure 1. Water retention curves for the investigated loamy and sandy soils without (loam 1 and sand 1) and with (loam 2 and sand 2) groundwater influence

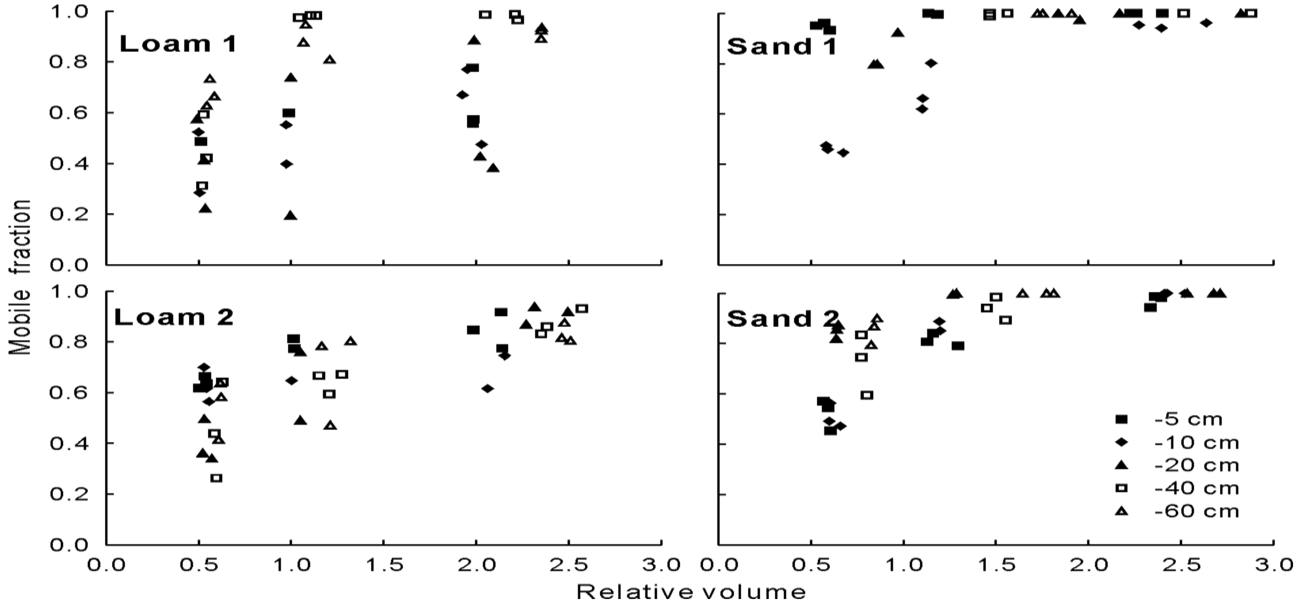

Figure 2. Calculated mobile water fraction relative to the soil water content in the investigated loamy and sandy soils without (loam 1 and sand 1) and with (loam 2 and sand 2) groundwater influence, as a function of the relative applied solution volumes determined at five different pressure head

While the applied volumes V a equalled 0.5, 1.0 and 2.0 times of the mean sample total pore volume, results were expressed as a relative applied volume v, defined in function of the applied volume and the sample water content at the respective pressure head:

$$v = V_a / V\theta_h \qquad (5)$$

where V is the total sample volume and $\theta_h$ is the water content at a respective pressure head.

The retention data for the sandy soils showed a greater water content range on the studied pressure head intervals, corresponding to a higher dispersion of *v* values.

The two sandy soils, but especially sand 1, showed mobile water fractions close to 1 even for small relative volumes of applied water. A distinct tendency for different pressure heads were not observed from these data, indicating that almost all water fractions participated in movement within the studied pressure head range. This is in agreement with the general idea that water in sandy soils is retained in interconnected pores with large diameters. The loamy soils showed higher immobile water contents. In the case of loam 1, there seemed to be a tendency of increasing $\Theta_m$ at higher pressure heads. Higher $\Theta_m$ in drier conditions is to be expected, as very large pores, responsible for almost all water transport and thus reducing $\Theta_m$ under wet conditions are not available for transport at higher pressure heads.

To quantify soil water mobility, a simple asymptotic equation is suggested to be fitted to data:

$$\Theta_m = v / (\alpha + v) \qquad (6)$$

where the dimensionless parameter *a* determines the shape of the curve. Low values of *a* indicate a steep curve, which reaches high values of $\Theta_m$at low values of *v*. No significant differences in *a* values were found between different pressure heads, but regression to all data obtained for one soil led to significant differences between the sandy and loamy soils (Table 2). This suggested a significant correlation between α and n from Eq. and *a* from Eq. 6, however, present data were insufficient to confirm this hypothesis.

Table 2. Mean values and 95% intervals for parameter a (Eq. 6) for the different investigated loamy and sandy soils

| Soil | Mean | 95% minimum | 95% maximum |
|---|---|---|---|
| Loam 1 | 0.5311 | 0.3665 | 0.6958 |
| Loam 2 | 0.4947 | 0.4118 | 0.5776 |
| Sand 1 | 0.1623 | 0.1010 | 0.2236 |
| Sand 2 | 0.2286 | 0.1722 | 0.2851 |

Eq. 6 yields $\Theta_m = 0$ for $v = 0$ and tends to 1 for high values of *v*. Alternatively, a parameter might be added to Eq. 6 to account for the fact that, especially in soils with higher clay contents, a fraction of soil water might be immobile even at very high flow volumes. Thus:

$$\Theta_m = v\Theta^*_m / (\alpha + v) \qquad (7)$$

where $\Theta^*_m$ represents the high flow volume mobile fraction. Regressions to this equation with present experimental data resulted in values for $\Theta^*_m$ close to 1 for all soils, indicating that was (almost) no immobile water in these soils at very high flow conditions.

## CONCLUSIONS

Soil water mobility was shown to be a function of applied water volume and could be parameterized by fitting a simple one- or two-parameter equation to experimental data. However, no relation between soil water mobility and pressure head could be established with data from the present experiment.

Sandy soils showed higher mobility than loamy soils at low values of applied solute volumes. As a consequence, under less intense leaching scenarios common to the studied region in Germany, nutrient retention in the immobile water fraction should be taken into consideration in these soils. The establishment of physical relations between soil water mobility and other soil hydraulic functions should be an object of further investigation, allowing the more routinely determined retention and conductivity properties to be translated in soil water mobility.

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