Saturated Hydraulic Conductivity as Parameter in Modeling Applications – Comparison of Determination Methods

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Abstract
The saturated hydraulic conductivity is a soil parameter which is broadly used to describe physical characteristics of soil. Many methods for its determination were developed, but still no standard was established. Different methods yield varying results which has to be considered in further interpretation. In this study, values for saturated conductivity were measured in the lab by falling head method as well as derived from tension infiltrometry in the field and evaporation method in the lab. The results were evaluated with regard to their further use as key parameter of hydraulic soil properties. The differences between values from evaporation method and from the other two methods were considerable and the former seem to underestimate saturated conductivity. Hence, an appropriate procedure for determination of saturated hydraulic conductivity will base on tension infiltrometry, falling head method or a combined calculation using results of both methods.

Keywords: saturated hydraulic conductivity, methodology, hydraulic soil properties

Introduction and Objectives
The saturated hydraulic conductivity, K_s, plays a central role in soil physical applications like modeling of soil water dynamics or characterization of soils. It may be measured directly by means of relatively convenient lab or field methods as well as calculated by pedotransfer functions or by fitting procedures to data from unsaturated flow experiments. Dane and Topp (2002) give a comprehensive collection of standard methods for measuring hydraulic conductivity of soil. In former studies, Mohanty et al. (1994), Gribb et al. (2004), or Jacka et al. (2014) compared measurement methods for K_s and demonstrated comparable mean results for some certain methods but also a considerable variability due to measurement setup.

This study presents recent part results of a research project which follows the intention to describe the alterations of hydraulic soil properties (HSP) as reaction to agricultural soil management or land-use changes (look at: spordyn.boku.ac.at). As a concretion for HSP, soil water retention curve, $\theta(\Psi)$, and conductivity curve, $K(\Psi)$ are used and determined using a combination of several field and lab methods. Consequently, K_s is a major parameter which is included in model approaches to describe the mentioned functions (e.g. Peters, 2013; Gardner, 1958) and affects results of further applications like soil water dynamics modeling considerably. Hence, the question how to obtain an appropriate value for K_s of examined soils is crucial.

Materials and Methods
In the presented study, data from 119 samples were analysed using three different methods for measuring hydraulic conductivity of the sample soils:

1. measurement of K_s in the lab by means of the falling head method after Dane and Topp (2002), undisturbed soil core in steel ring, d = 84mm, h = 50mm

2. measurement of unsaturated conductivity in the field with a tension infiltrometer of type hood infiltrometer after Schwärzel and Punzel, 2007, diameter of hood = 124mm.
3. evaporation method after Peters and Durner (2008) using HYPROP measuring devices, same soil core as method 1.

The methods used for measurement and subsequent calculation of K_s will be called by the following short terms in the subsequent paper: falling head lab method: LAB, tension infiltrometry using hood infiltrometer: HI, evaporation method using HYPROP-devices: HYP. Whereas LAB yields K_s directly, when using methods HI and HYP K_s has to be determined by fitting a certain model to the measurements of unsaturated conductivity at a given matric potential, Ψ. The intention of this study is to compare measurement methods and therefore a simple model after Gardner (1958) was used, which has only 2 fitted parameters, K_s and α (Eq. (1)). Hence, the comparability of K_s-values amongst the methods should be optimal because of the low number of parameters.

$$K(\psi) = K_s \exp(\alpha \ \psi) \tag{1}$$

Soil samples for the analysis were collected from arable land at three study sites in Lower Austria: Obersiebenbrunn, Hollabrunn, and Pyhra. Some basic data about the study sites are given in 2. The sampling points were arranged in transects across the experimental fields and placed in the centre between crop rows. Measurements started with infiltration experiments and after a short waiting time for surface drying (to minimize modifications of the soil core surfaces), soil core samples were taken carefully from the centre of the infiltration circle and included the topsoil from 0-5 cm depth. Hence, every method was applied on exactly the same piece of soil although the treated volume in the infiltration experiments was obviously larger.

Table 1: study site data; MAP = mean annual precipitation, SOC = Soil Organic Carbon; textural soil type classified after ÖNORM L 1050

	Crop 2016	soil type (texture)	soil type	MAP	SOC	n
Obersiebenbrunn	winter wheat	sandy loam	Chernozem	520 mm	1 - 2%	42
Hollabrunn	sunflower	loamy silt	Chernozem	519 mm	1 - 2%	69
Pyhra	winter ray / meadow	sandy loam	Pseudogley	860 mm	1 - 2%	8

Results and Discussion

Figure 1 shows the empirical density functions of log K_s for the three used methods. A visual interpretation leads to the interpretation that the values obtained by HYP are significantly different to these from the two other methods LAB and HI. Figure 2 emphasizes the interpretation. A Wilcoxon signed-rank test resulted in the rejection of the null-hypothesis that LAB and HI give results with identical location.

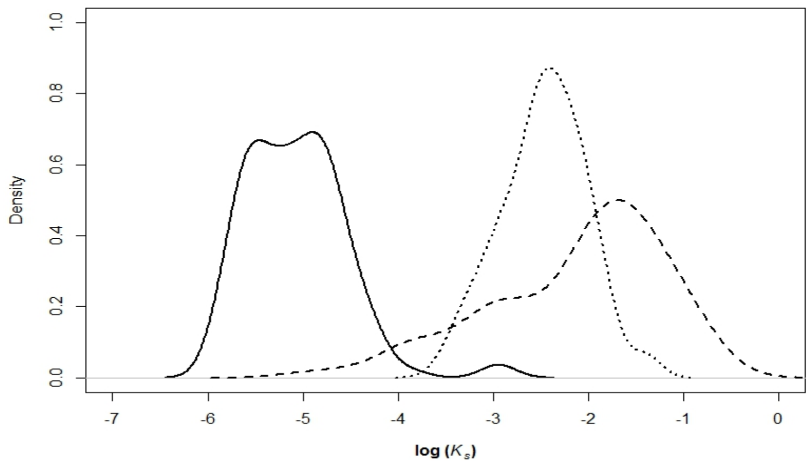

Figure 1: empirical density functions of log-conductivity values;
continuous line: HYP, dashed line: LAB, dotted line: HI

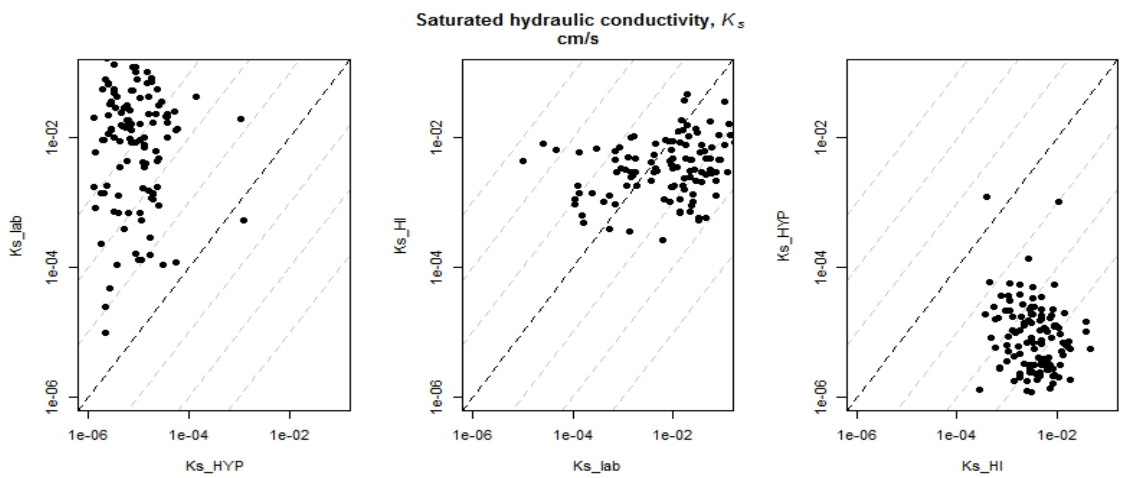

Figure 2: comparison of measured values per method;
strong dashed line is x=y, gray dashed lines visualize residuals of one order of magnitude each

The quantitative differences between values obtained by the different methods are given in 2. Calculations followed equation (2) where *function* stands for the used function (mean, standard deviation, maximum), *i* for a consecutive number of the sample and *parameter* for the result given in 2. Hence, the K_s-measurements of HYP are on average nearly three orders of magnitude smaller than these of LAB and HI.

$$parameter = function\,[\log(x_{i,Method\ A}) - \log(x_{i,Method\ B})] \qquad (2)$$

Table 2: statistical parameters of log-differences between measurement methods; calculation after Eq.(2)

	mean	sd	max
HI – LAB	-0.34	0.92	2.64
LAB – HYP	2.62	0.74	3.99
HI – HYP	2.96	1.07	5.10

Conclusions

The purpose of this study was to evaluate the three methods for measurement of K_s which are used in the overall project for their usability in parametrization of hydraulic soil properties. As a major outcome, it has to be stated, that the K_s-values from fitting a model to measured values from evaporation experiments on undisturbed soil cores (HYP) are significantly lower than those of other methods. The reason for this phenomenon is most likely the measurement range of the evaporation method. Thereby, water flow in the soil core is detectable only at pF > 1 – 1.5. Hence, the wettest part of the conductivity curve is not represented in the measurements, but obviously crucial for *Ks*.

The large distance between values which were derived from measurements in the drier part of the conductivity curve (HYP) and of the wetter part (HI, LAB) may be a result of a bimodal pore size distribution. Furthermore, the surprisingly small average deviation between LAB and HI may be interpreted as a signal of vicinity to an appropriate value of K_s for modeling or parametrization applications. Nevertheless, the high standard deviation and subsequently the coefficient of variation of nearly 3 leads to the conclusion that the number of samples in further studies has to be chosen high enough to assure meaningful results.

In the ongoing work on this project, the comparison of methods will be continued, also external data to extend the data base is highly welcome and appreciated. Our results indicate that a combination of the falling head method and the tension infiltrometry seems most promising and could be extended with an appropriate scaling method to allow also for spatial variability.

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