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# Measurement of hydraulic properties of growing media with the HYPROP system

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## Abstract

Knowledge of hydro-physical properties is an essential prerequisite for assessing the suitability and quality of growing media. The method used for sample preparation is important for the measurement results. Three different sample preparation methods were compared. The methods differed in terms of the way the 250°cm $^3$ steel cylinder was filled and the height of preloading. Measurements on loosely filled cylinders were included. The comparison was carried out on 15 growing media using the HYPROP device. HYPROP enables a complex analysis of the hydro-physical properties with high accuracy and reproducibility. The water retention curve, the unsaturated hydraulic conductivity function, the dry bulk density, the shrinkage and the rewetting properties can be measured simultaneously. The air capacity and the amount of plant-available water in pots depend on the height of the pot. In the field, it is related to the field capacity. The quality assessment was carried out both for flowerpots of different height and for field conditions with free drainage. Loosely filled samples consolidated hydraulically shortly after the start of the measurement. These geometric changes can be taken into account with the HYPROP. The sample preparation method – preloading or loose filling – yielded significantly different results for the pore volume, dry bulk density, plant available water and air capacity. The total pore volume of the loosely filled cylinders varied between 86.8 and 95.2°% by vol. (preloaded 81.3 and 87.7°% by vol.). The most critical factor was the air capacity. Loosely filled substrate samples achieved the highest air capacities, but also did not reach the critical value of 10°% by volume in shallow flowerpots, e.g. in 10 cm pots with 5.8°% by volume. The sample preparation method, measurement and quality assessment of the hydro-physical properties of growing media should be adapted to the conditions of use – whether they are used in a field with free drainage or in pots or containers in greenhouses.

*Keywords:* sample preparation, water retention curve, unsaturated hydraulic conductivity function, Extended Evaporation Method (EEM), HYPROP

## Introduction

Knowledge of hydro-physical properties is an essential prerequisite for assessing the suitability of soils in agriculture and of growing media in horticulture (Raviv and Lieth, 2008, Schindler et al., 2015, Schmilewski, 2017). Beside the capillarity, the tendency to shrinkage and swelling and the rewetting properties, the most important hydro-physical variables are the air capacity and the plant-available water.

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According to the Garden Industry Association (IVG, Schmilewski, 2017), the average total pore volume of growing media is 94°% by volume. Such high values could not be confirmed by Schindler and Müller (2017a). Previous studies (Schindler and Müller 2017a) showed that the air capacity can assume especially critical values in shallow flowerpots. The air capacities recommended by different authors in Schmilewski (2017), however, varied between 10 and 40°% by vol. This range of air capacities is in strong contradiction to the results gained by Schindler and Müller (2017a). In that study, the air capacity of 36 different growing media was a crucial variable. The limit of 10°% by vol. was exceeded in only very few cases. The study included growing media consisting of pure peat, pure coir, peat-free substrates and very different mixtures of peat with compost, bark, perlite and other materials. The average air capacity in line with DIN EN 13041 (2012) was 5°% by vol. (max. 17.5°% by vol., min. 1.6°% by vol., standard deviation 3.3°% by vol.).The question is, how can these extreme differences be explained and what is the cause – the measurement method, the evaluation procedure, the sample preparation, the growing medium itself or other factors?

The standard means of measuring hydro-physical properties is the sandbox method (Raviv and Lieth, 2008, DIN EN 13041, 2012). The measurement is time-consuming, and the results are limited to a tension range between saturation and 100°hPa. Only the water retention properties can be measured as the basis for calculating the air capacity and the plant-available water. The HYPROP (HYdraulic PROPerty analyzer), however, simultaneously enables an accurate, effective and reproducible measurement of all the hydro-physical properties required of growing media, including capillarity, shrinkage and re-wettability (Schindler et al., 2017a).

The sample preparation method for measuring and evaluating the physical properties of growing media is an important issue. Methods are used with mechanical preloading (PPO in Wever, 1999; Schindler et al., 2017a) or loosely filled cylinders with pre-wetted material (DIN EN 13041, 2012). These individual procedures can lead to different results.

The assessment of growing media quality must be directly related to horticultural practice. In practice, flowerpots are loosely filled with the growing medium by hand or with a potting machine (Fig. 1), planted and watered so that water emerges at the base (Fig. 2). The preparation and measurement of hydro-physical properties must correspond to these conditions to be sufficient. The conditions in the field are different. There, the substrate is under free drainage and can be driven over with machines. Here, we studied the effect of different sample preparation procedures. The measurements were carried out with the HYPROP system, focusing on the air capacity and the plant-available water. The following results are presented and discussed.

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**Figure 1.** Potting machine

**Figure 2.** Samples on a water-saturated fleece after filling and planting in the market

## Materials and Methods

### *Hydro-physical basics*

DIN EN 13041 (2012) defines the air capacity as a fixed value. It is calculated as a difference in water content ranging between saturation and a tension of 10°hPa. This value is suitable to compare growing media, but of limited significance for practical issues such as evaluating the air and water capacity in flowerpots or in the field.

The air and water capacity in flowerpots are not fixed values, but depend on the height of the pot. In horticultural practice, flowerpots are watered after filling and planting so that water drains at the base (Fig. 2). Then, the flowerpots are placed on a water-saturated fleece. In this case, there is a tension of 0 at the base of the flowerpot. The water and air content in the flowerpots is calculated from the water retention curve (Eq. 1, Fig. 3, left). The air capacity of 10hPa as defined in DIN EN 13041 (2012) is assumed to be available throughout the pot (Fig. 3, right). The air capacity in the field (Fig. 3, right) is a fixed" value in the profile with free drainage and corresponds to the water content at field capacity (FC) at 60°hPa (AG Boden, 2005).

$$\int_0^{\Psi} \Theta(\Psi)\,dz \qquad (1)$$

With Ψ being tension and Θ being water content.

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### *Sample preparation procedures*

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*Method A*

The cylinder (250 cm$^3$, 5 cm high) was loosely filled with the substrate directly from the package (Schindler et al., 2017). The water content of the sample was not changed. The sample surface was loaded for one minute with a 10 kg weight (0.2 kg cm$^{-2}$). A second cylinder was placed on top of the first, half-filled with substrate, and the compression procedure was repeated. The surface was smoothed. The sample was saturated and prepared for the HYPROP measurement.

*Method B*

The substrates were loosely poured into plastic tubes (diameter 15 cm, height 60 cm). The pipes were placed in a bowl with water and saturated by capillary action for about 48 hours (Fig. 4).

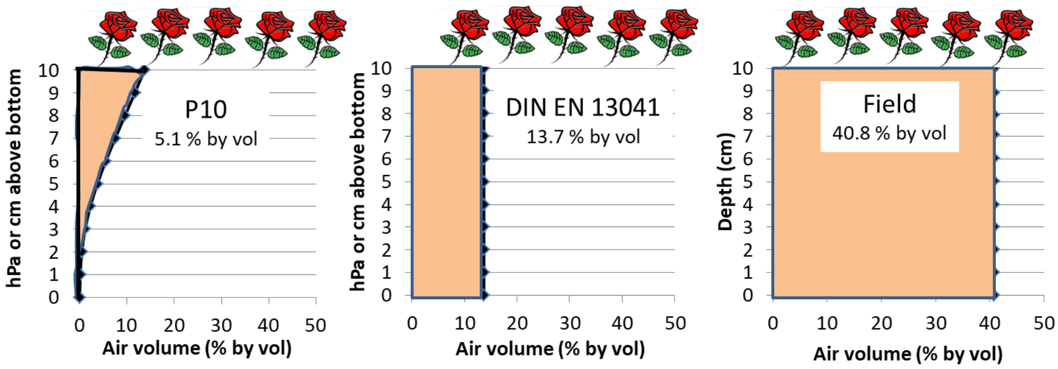


**Figure 3.** Air capacities in 10°cm high pots: left, Air_DIN at 10°hPa: middle and right: in the field. Substrate 25W1.

After capillary saturation, the tension at the surface varied between 50 to 55°hPa. In the following, the upper 5 cm of the substrate were removed and mixed and the 250 cm$^3$ cylinders were filled loosely. The filling took place in 2 stages. First the cylinder was completely filled and rammed onto the table 5 times by hand. The sample material compressed hydraulically. A second cylinder was then placed on top, half-filled with substrate and the two were rammed onto the table another five times. The second cylinder was removed and the sample surface was smoothed. The samples were saturated and the measurement with the HYPROP could start.

*Method C*

Comparable to practice, the substrate was loosely poured into the cylinder directly from the package. The sample was saturated, the surface smoothed and prepared for the HYPROP measurement. Immediately after the start of the measurement, the sample material consolidated hydraulically. The consolidation process was finished shortly after the start of the measurement at a tension between 1 and 3°hPa. The geometric changes were taken into account with the HYPROP. This procedure is

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comparable to DIN EN 13041 (2012), the difference being that the DIN-defined hydraulic consolidation already took place before the measurement (capillary pre-saturation to 50°hPa).


**Figure 4.** Capillary saturation to 50°hPa.

## Growing media

Table 1 gives an overview of the composition of the tested growing media.

**Table 1**. Composition of the substrates for the comparison of sample preparation

| No. | Ingredients |
|---|---|
| 9W | 75°% H3-H5, H6-H7, Co, Cl, Ca |
| 9W1 | 80°% H3-H5, H6-H7, Ko, Cl |
| 16W | H2-H5, G, R, Ca |
| 25W | 60°% H3-H5, H6-H7, R, G, Co, Ca |
| 25W1 | 60°% H3-H5, H6-H7, Co, Cl, P |
| 27W | 50°% H3-H5, G, R, Cl |
| K1 | 80°% Hh,(H3-H4), 20°% Hh (H7-H9), Cl, gramoMicro |
| K2 | 45°% Hh /H3-H4), 30°% Hh (H7-H9), 25°% F, Cl, gramoMicro |
| HTC_150C | K1 plus 10°% HTC, 150°C |
| HTC_150D | K1 plus 20°% HTC, 150°C |
| HTC_170D | K1 plus 20°% HTC, 170°C |
| HTC_190C | K1 plus 10°% HTC, 190°C |
| HTC_190D | K1 plus 20°% HTC, 190°C |
| HTC_190E | K1 plus 30°% HTC, 190°C |
| DK | 50°% Hh (H2-H4), 50°% Hh (H7-H9), Cl, Ca |

Hh – bog peat, H3 – degree of decomposition 3, HTC – hydrothermally carbonized plant material at different temperatures, F – compost from forest residues, Ca – lime, G – compost from garden residues, Cl – clay, Co – coir, P – perlite, R – bark mulch.

### *Hydro-physical measurement with HYPROP*

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The HYdraulic PROPerty system (HYPROP, UMS 2012) was used to simultaneously measure the water retention function (pF curve), the hydraulic conductivity function (K-function) and dry bulk density in the range between saturation and the permanent wilting point (Fig. 5; Schindler et al., 2010; Schindler et al., 2017a). With minimal additional effort, the shrinkage and rewetting properties can be quantified simultaneously (Schindler et al., 2015). The function is covered with a large number of data. The measurement accuracy and reproducibility are high (Schindler et al., 2012). The measured values are recorded online. It is possible to measure multiple samples in parallel.

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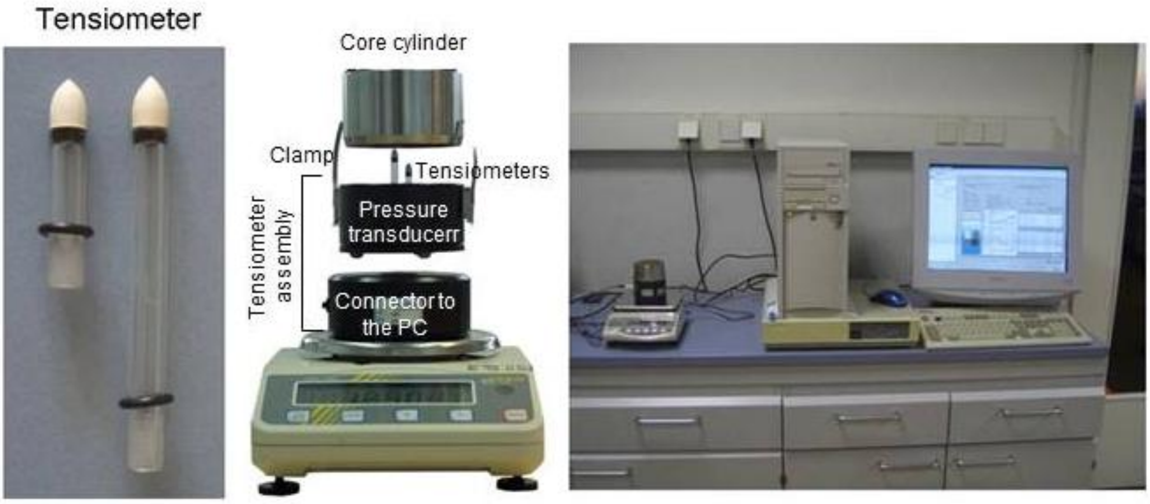


**Figure 5.** HYPROP system

**Brief description**: Hydro-physical properties of soils or growing media can be measured with the HYPROP at undisturbed or disturbed cylinder samples (100 or 250 $cm^{-3}$). The sample is saturated, connected to the HYPROP and placed on a scale. The scale and the HYPROP are connected to the PC. The sample surface is exposed to free evaporation and the measurement data (tensions, sample mass) are recorded at time intervals. When the evaporation measurement is finished, the sample is dried at 105°C in the oven to measure the amount of residual water and the dry bulk density. The evaluation (calculation, fitting, data export) takes place with the HYPROP-Fit software (UMS 2015). The measurement takes about 3 to 10 days and depends from the water content of the sample. The measurement can be stopped at any tension between saturation and the permanent wilting point (pWP, AG Boden, 2005).

## Results and Discussion

The high reproducibility of the HYPROP measurements is shown as an example in Fig. 6 for 3 replicates of substrate K1. Statistical results for the replicates are given by the HYPROP software. The results of sample preparation are summarized in Table 2 and Table 3. Methods A and B were carried out with mechanical preloading. Method B corresponds to the PPO standard (Wever, 1999).

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Method C was without any mechanical preloading. This method was close to horticultural practice and comparable to DIN EN 13041 (2012).

Fig. 7, left shows the example of minor differences in the water retention functions of the sample preparations A and B with preloading for substrate 25W1 as an average function of three replicates. Table 2 presents average values of three replicates as the basis for statistical evaluation (average of the tested substrates, standard deviation and t-test (Excel, Windows 10). The air capacity in 10°cm high pots (A: 3.2% by vol. and C: 5.4°% by vol.) did not reach the 10°% by vol. threshold value (Raviv and Lieth, 2007; Fischer, 2010). The air capacities as defined in DIN EN 13041 (2012) were, as expected, more than twice as high. With the exception of air and water, no other variables were significantly different. The dry bulk density (A: 0.23 g cm$^{-3}$, B: 0.22 g cm$^{-3}$) and the pore volume differed only slightly (A: 81.7°% by vol., B: 81.5°% by vol.) but did not come close to the values in Schmilewsky (2017) of 90°% by vol. and more. Under field conditions, the air capacity was very high (A: 36.9°% by vol., B: 38.3°% by vol.); however, due to this, the plant-available water was reduced by 10°% by vol. and more (A: 24.2°% by vol., B: 22.7°% by vol.).

The results of comparing methods B and C are presented in Table 3 and Fig. 7, right. The substrate in the loosely filled cylinders (C) compacted hydraulically shortly after the start of the measurement. The sample height and the volume decreased from 5 cm to a minimum of 4.5 cm, or from 250 to 225 cm$^3$. These geometrical changes were taken into account by the HYPROP Fit software. This process is comparable to the hydraulic compaction during pre-saturation as defined in DIN EN 13041 (2012), but more effective because no pre-saturation step to 50°hPa is required. As expected, the differences between Method B with preloading and the loosely filled cylinders from Method C were highly significantly different for all variables. The pore volume exceeded 90°% by vol. with Method C. These values were comparable to the results gained by Schmilewski (2017). With Method B, the average pore volume was 83°% by vol. The air capacities in shallow, loosely filled pots (Method C) were considerably higher than with the preloaded samples of Method B (C: 5.8°% by vol., B: 2.8°% by vol.). However, even when the cylinder was loosely filled (C), the air capacity was far from the threshold value of 10°% by vol. The air capacities Air_$_{DIN}$ were also twice as high as Air P10. In higher pots, and especially under field conditions, the air capacity was sufficient. For growing media with sufficient air capacity in the upper part of the pot, intelligent knowledge-based water management can reduce the air problem. Under field conditions, however, the plant-available water was reduced by more than 10°% by vol. compared to cultivation in pots.

**Table 2.** Hydro-physical results of growing media after applying sample preparation methods A and B.

| M[1)] | No. | DBD | PV | FC | Air_$_{DIN}$ | Air | | | | Water | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10°hPa | P10 | P20 | P30 | Field | P10 | P20 | P30 | Field |

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| | | gcm$^{-3}$ | %°by vol | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 9W | 0.24 | 81.8 | 43.4 | 4.5 | 2.0 | 8.8 | 15.5 | 38.4 | 43.2 | 36.4 | 29.7 | 18.4 |
| A | 9-1W | 0.22 | 87.1 | 46.8 | 7.0 | 3.0 | 10.0 | 18.9 | 40.3 | 41.8 | 34.7 | 25.8 | 25.5 |
| A | 16W | 0.26 | 75.9 | 37.0 | 14.9 | 6.7 | 14.4 | 19.8 | 38.9 | 37.2 | 29.6 | 24.2 | 17.5 |
| A | 19W | 0.20 | 82.9 | 51.2 | 2.2 | 1.1 | 4.9 | 15.2 | 31.7 | 35.6 | 31.8 | 21.5 | 25.0 |
| A | 25W | 0.22 | 81.3 | 44.0 | 6.6 | 2.7 | 9.9 | 17.5 | 37.3 | 40.0 | 32.9 | 25.3 | 35.1 |
| A | 25-1W | 0.24 | 82.2 | 44.2 | 8.9 | 5.3 | 11.0 | 17.8 | 38.0 | 40.0 | 34.3 | 27.5 | 25.7 |
| A | 27W | 0.25 | 80.8 | 46.8 | 3.4 | 1.4 | 6.4 | 15.5 | 34.0 | 36.7 | 31.7 | 22.6 | 22.4 |
| B | 9W | 0.22 | 80.7 | 38.8 | 14.0 | 7.3 | 14.8 | 21.4 | 41.9 | 40.1 | 32.6 | 26.0 | 23.9 |
| B | 9-1W | 0.18 | 84.4 | 44.1 | 13.6 | 6.9 | 14.5 | 20.9 | 40.4 | 38.1 | 30.5 | 24.1 | 24.3 |
| B | 16W | 0.28 | 78.8 | 43.2 | 10.8 | 4.8 | 12.4 | 17.0 | 35.6 | 36.1 | 28.5 | 23.8 | 21.4 |
| B | 19W | 0.19 | 83.4 | 49.0 | 4.3 | 2.5 | 8.7 | 16.2 | 34.4 | 36.0 | 29.8 | 22.3 | 24.4 |
| B | 25W | 0.19 | 81.1 | 39.8 | 14.6 | 7.1 | 15.6 | 21.6 | 41.3 | 39.1 | 30.6 | 24.6 | 21.3 |
| B | 25-1W | 0.23 | 80.8 | 40.8 | 13.6 | 6.4 | 14.7 | 20.4 | 40.0 | 39.5 | 31.2 | 25.5 | 19.9 |
| B | 27W | 0.26 | 81.5 | 47.1 | 6.6 | 2.5 | 7.8 | 15.6 | 34.4 | 36.4 | 31.1 | 23.3 | 23.7 |
| A | Av | 0.23 | 81.7 | 44.8 | 6.8 | 3.2 | 9.3 | 17.2 | 36.9 | 39.2 | 33.1 | 25.2 | 24.2 |
| B | Av | 0.22 | 81.5 | 43.3 | 11.1 | 5.4 | 12.6 | 19.0 | 38.3 | 37.9 | 30.6 | 24.2 | 22.7 |
| A | stabw | 0.02 | 3.3 | 4.3 | 4.2 | 2.1 | 3.1 | 1.8 | 3.0 | 2.8 | 2.3 | 2.8 | 5.8 |
| B | stabw | 0.04 | 1.9 | 3.8 | 4.1 | 2.1 | 3.2 | 2.6 | 3.3 | 1.7 | 1.3 | 1.3 | 1.8 |
| t-test | | 0.20 | 0.79 | 0.33 | 0.05 | 0.06 | 0.02 | 0.13 | 0.21 | 0.06 | 0.003 | 0.15 | 0.56 |

1) Preparation method, DBD - dry bulk density, PV - total pore volume, FC - field capacity at pF 1.8 (AG Boden 2005), stabw - standard deviation, P10 - pot, 10°cm high, Av - average.

According to information from the Garden Industry Association (IVG), the average pore volume of gardening substrates is between 90 and 94°% by vol. The results from these studies confirmed these high pore volumes only for the samples of Method C. In those, the pore volume varied between 86.8 and 95.2°% by volume. The recommended air capacities published in Bohne (2006), Raviv and Lieth (2007), Huntenberg (2016), Fischer (2016) and Schmilewski (2017) varied between 10 and 40°% by vol. This range is in strong contrast to the results of this paper and Schindler et al., (2017a, b, c). The main reason for the differences is seen in the methodology.

As defined in DIN EN 13041 (2012), the air capacity corresponds to the difference in the water content, comparing the total pore volume and the water content at a tension of 10°hPa. However, this value cannot be determined exactly with the standard method (sandbox), since the tension applied is related to the centre of the sample. The tension at the lower and upper edges of the sample is -7.5 and -12.5°hPa, respectively. Linear averaging is not permitted and can lead to uncertainties. Another uncertainty arises from the determination of the total pore volume, since only fixed particle density values (also known as the true density or particle density) are used of the mineral and organic substance. This could result in very high values for the total pore volume and also for the air capacity, whose relevance for horticultural practice has to be questioned. The air capacity and the plant-available water are different under field conditions compared to pots.

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The measurement and evaluation methods for assessing the quality of the hydro-physical properties of growing media must be adapted to the conditions of use. Under field conditions, the air capacity and the amount of plant-available water are calculated from the field capacity (AG Boden, 2005). In the greenhouse, the height of pots and containers must be taken into account. In addition, the sample preparation should also be adapted. Under field conditions, the substrate may be walked on by people and driven over by machines, so sample preparation methods with preloading are required and used (PPO in Wever, 2012 and Schindler et al., 2017a). Pots in the greenhouse are filled loosely. The samples for hydro-physical measurements should also be prepared accordingly. It has been shown that there are significant differences in air capacity and the plant-available water between the sample preparation with and without preloading. Method C is comparable to DIN EN 13041 (2012). The difference lies in the way hydraulic consolidation occurs. According to DIN EN 13041 (2012), this happens in the 50°hPa cylinder. With the HYPROP, the sample consolidated directly in the cylinder during the measurement. Under these conditions, it would not be possible to measure the retention properties in the sandbox. However, HYPROP can take the geometric changes into account. This can save equipment, labour, time and money.

Intelligent growing media water management requires knowledge of hydro-physical properties. The air capacity in shallow pots can assume critical values.

**Table 3:** Hydro-physical results of growing media after applying sample preparation methods B and C.

| M[1)] | No. | DBD | PV | FC | Air_DIN | Air | | | | Water | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10°hPa | P10 | P20 | P30 | Field | P10 | P20 | P30 | Field |
| | | gcm$^{-3}$ | %°by vol. | | | | | | | | | | |
| B | K1 | 0.22 | 83.5 | 47.6 | 6.2 | 2.7 | 7.3 | 15.4 | 35.8 | 39.2 | 34.6 | 26.5 | 29.5 |
| B | K2 | 0.25 | 82.9 | 49.5 | 5.5 | 2.8 | 7.4 | 12.0 | 33.4 | 36.3 | 31.7 | 27.1 | 28.0 |
| B | HTC_150C | 0.23 | 81.3 | 49.9 | 6.3 | 3.6 | 7.8 | 11.6 | 31.3 | 34.4 | 30.3 | 26.4 | 31.2 |
| B | HTC_150D | 0.22 | 80.5 | 45.6 | 7.6 | 2.1 | 7.8 | 12.9 | 34.9 | 38.5 | 32.8 | 27.7 | 27.9 |
| B | HTC_170D | 0.23 | 82.6 | 49.5 | 9.5 | 3.8 | 9.3 | 13.6 | 33.1 | 34.9 | 29.4 | 25.1 | 28.2 |
| B | HTC_190C | 0.24 | 84.9 | 54.5 | 2.9 | 0.9 | 4.2 | 22.5 | 30.3 | 43.7 | 32.1 | 22.1 | 29.2 |
| B | HTC_190D | 0.23 | 83.3 | 55.0 | 3.0 | 1.0 | 3.6 | 7.3 | 28.4 | 33.4 | 30.8 | 27.1 | 30.2 |
| B | HTC_190E | 0.22 | 80.6 | 50.8 | 7.9 | 4.9 | 9.2 | 12.7 | 29.9 | 30.2 | 25.9 | 22.5 | 26.9 |
| B | DK B170 | 0.17 | 87.7 | 47.4 | 8.7 | 3.3 | 10.0 | 24.5 | 40.3 | 42.5 | 35.9 | 21.3 | 27.6 |
| C | K1 | 0.19 | 95.2 | 46.7 | 11.6 | 7.6 | 14.4 | 28.6 | 48.6 | 47.9 | 41.1 | 26.9 | 27.7 |
| C | K2 | 0.20 | 89.8 | 41.6 | 16.3 | 8.2 | 16.7 | 22.9 | 48.2 | 44.6 | 36.1 | 29.8 | 19.1 |
| C | HTC_150C | 0.21 | 93.5 | 43.3 | 17.7 | 6.4 | 14.9 | 21.7 | 51.8 | 55.2 | 46.6 | 39.8 | 20.7 |
| C | HTC_150D | 0.19 | 88.2 | 40.7 | 13.3 | 4.0 | 13.0 | 20.1 | 47.5 | 48.3 | 39.4 | 32.3 | 21.6 |
| C | HTC_170D | 0.22 | 90.6 | 42.5 | 12.9 | 5.8 | 13.6 | 20.5 | 48.0 | 46.8 | 39.0 | 32.1 | 19.8 |
| C | HTC_190C | 0.22 | 92.8 | 50.1 | 9.6 | 5.4 | 11.4 | 27.5 | 42.7 | 43.6 | 37.6 | 21.5 | 26.4 |
| C | HTC_190D | 0.20 | 91.0 | 42.5 | 16.7 | 7.7 | 17.0 | 23.8 | 48.6 | 45.5 | 36.1 | 29.4 | 20.5 |
| C | HTC_190E | 0.22 | 86.8 | 44.5 | 10.3 | 4.1 | 11.2 | 17.4 | 42.3 | 42.4 | 35.2 | 29.1 | 22.1 |
| C | DK B170 | 0.17 | 88.8 | 47.0 | 7.4 | 2.9 | 8.6 | 25.0 | 41.9 | 44.7 | 39.0 | 22.6 | 27.9 |
| B | Av | 0.22 | 83.0 | 50.0 | 6.4 | 2.8 | 7.4 | 14.7 | 33.0 | 37.0 | 31.5 | 25.1 | 28.7 |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Av | 0.20 | 90.7 | 44.3 | 12.9 | 5.8 | 13.4 | 23.1 | 46.6 | 46.6 | 38.9 | 29.3 | 22.9 |
| B | stabw | 0.022 | 2.3 | 3.1 | 2.3 | 1.3 | 2.2 | 5.4 | 3.6 | 4.4 | 2.9 | 2.5 | 1.4 |
| C | stabw | 0.017 | 2.7 | 3.1 | 3.5 | 1.9 | 2.7 | 3.6 | 3.5 | 3.8 | 3.5 | 5.5 | 3.5 |
| t-test | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 |

1) Preparation method, DBD - dry bulk density, PV - total pore volume, FC - field capacity at pF 1.8 (AG Boden 2005), stabw - standard deviation, P10 - pot, 10°cm high, Av - average.

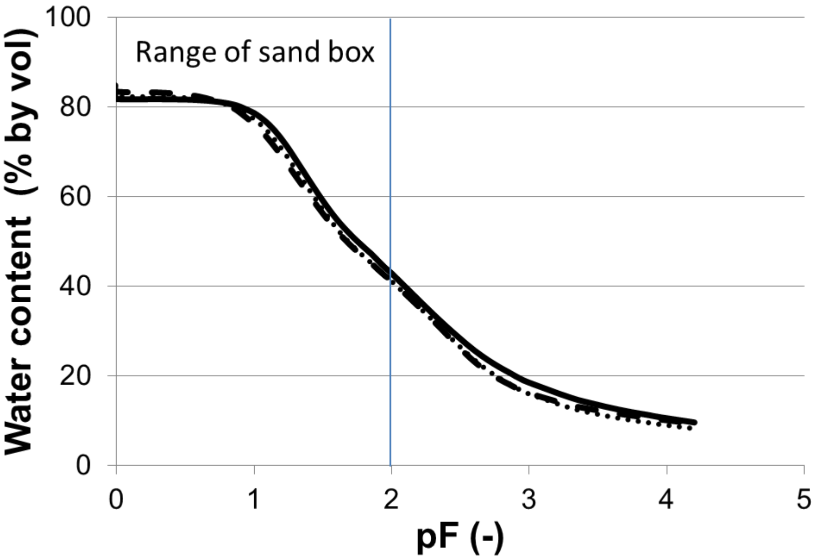


**Figure 6.** Reproducibility of water retention curves, K1 sample, preparation Method B, three replicates.

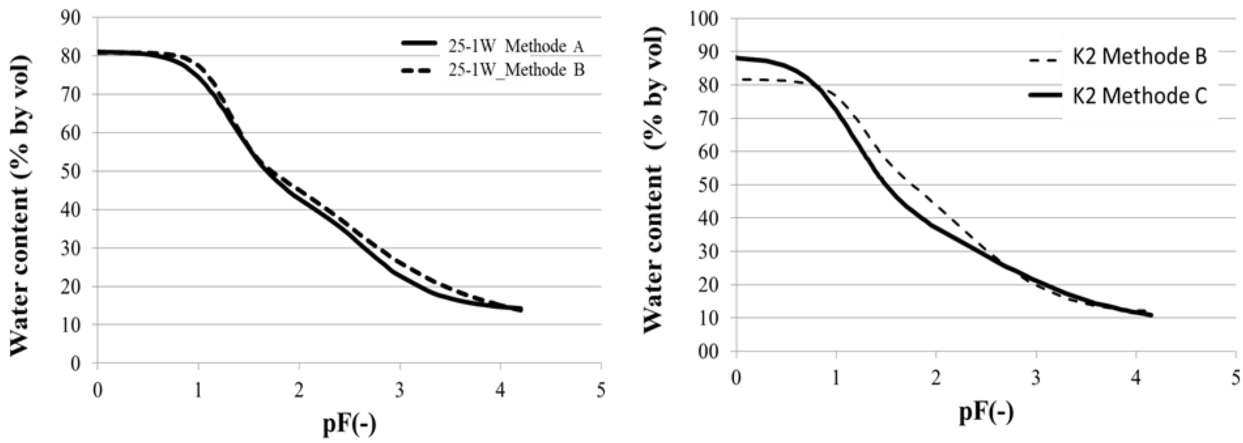


**Figure 7**. Example of the water retention functions, preparation methods A and B (left), B and C (right).

## Conclusions

1. HYPROP is an effective system for the complex measurement of hydro-physical properties of growing media with high quality and reproducibility. It is the basis for intelligent, knowledge-

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based air and water management in horticulture. Beside the water retention curve and the unsaturated hydraulic conductivity function, the dry bulk density, capillarity, shrinkage and rewetting properties can be simultaneously measured and enable a complex hydro-physical evaluation of soils and growing media.

2. The sample preparation method – preloading or loose filling – yielded significantly different results in terms of the pore volume, dry bulk density, plant-available water and (especially and most critically) air capacity.
3. The sample preparation method, the measurement and the assessment of the quality of hydro-physical properties of growing media must be adapted to the conditions of use: a field with free drainage or a greenhouse with pots or containers. The air capacity and the amount of plant-available water in pots depend on the height of the pot. In the field, they are related to the field capacity.
4. The air capacity as defined in DIN 13041 (2012) can be used to compare different growing media. However, this value is of limited significance for air and water management and quality assessment in horticulture.
5. For growing media with sufficient air capacity in the upper part of the pot, intelligent knowledge-based water management can reduce the air problem.
6. Further investigations are required to study how the sample preparation method affects the hydro-physical properties of a wide variety of growing media.

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**Merenje hidrauličkih osobina podloga za uzgoj sa HYPROP sistemom**

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**Izvod**

Poznavanje vodno-fizičkih svojstava je suštinski preduslov za procenu podobnosti i kvaliteta podloga za uzgoj. Metoda koja se koristi za pripremu uzoraka je važna za rezultate merenja. Upoređene su tri različite metode pripreme uzoraka. Metode su se razlikovale u pogledu načina punjenja čeličnog cilindra od 250°cm$^3$ i visine predopterećenja. Uključena su i merenja na slabo napunjenim cilindrima. Poređenje je obavljeno na 15 podloga za uzgoj pomoću HYPROP uređaja. HYPROP omogućava kompleksnu analizu -fizičkih svojstava sa visokom preciznošću i ponovljivošću. Kriva zadržavanja vode, funkcija nezasićene hidrauličke provodljivosti, zapremiska specifična masa, skupljanje i svojstva ponovnog vlaženja mogu se meriti istovremeno. Kapacitet vazduha i količina vode dostupne biljci u saksijama zavise od visine saksije. Na terenu je povezan sa poljskim vodnim kapacitetom t. Procena kvaliteta je vršena kako za saksije različite visine, tako i za terenske uslove sa slobodnom drenažom. Labavo napunjeni uzorci su hidraulički konsolidovani ubrzo nakon početka merenja. Ove geometrijske promene se mogu uzeti u obzir sa HYPROP -om. Metoda pripreme uzorka – prethodno punjenje ili rastresito punjenje – dala je značajno različite rezultate za zapreminu pora, zapreminska specifična masa suvog zemljišta, kapacitet vode i vazduha koji je dostupan biljci. Ukupna zapremina pora labavo ispunjenih cilindara varirala je između 86,8 i 95,2°% zapremine. (prednapunjeno 81,3 i 87,7°% po zapremini). Najkritičniji faktor je bio kapacitet vazduha. Slabo napunjeni uzorci supstrata postigli su najveće vazdušne kapacitete, ali takođe nisu dostigli kritičnu vrednost od 10°% zapremine u plitkim saksijama, npr. u posudama od 10°cm sa 5,8°% zapremine. Metod pripreme uzoraka, merenje i procenu kvaliteta vofizičkih svojstava podloga za uzgoj treba da budu prilagođeni uslovima upotrebe – bilo da se koriste u polju sa slobodnom drenažom ili u saksijama ili kontejnerima u plastenicima.

*Ključne reči:* priprema uzorka, kriva zadržavanja vode, funkcija nezasićene hidrauličke provodljivosti, metoda produženog isparavanja (EEM), HYPROP

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