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Water potential and hydraulic conductivity of peat growth media in containers during drying

Juha Heiskanen

TIIVISTELMÄ: KASVUTURPEIDEN VESIPOTENTIALIAALI JA VEDENJOHTAVUUS PAAKUISSA KUIVUMISEN AIKANA

Heiskanen, J. 1993. Water potential and hydraulic conductivity of peat growth media in containers during drying. Tiivistelmä: Kasvuturpeiden vesipotentialiaali ja vedenjohtavuus paakuissa kuivumisen aikana. *Silva Fennica* 27(1): 1–7.

The matric potential and unsaturated hydraulic conductivity of peat based growth media in containers was measured continuously as a function of drying. The particle size distribution and the water retention characteristics of the media were determined from parallel samples. The growth media used were a light, coarse graded *Sphagnum* peat, a medium graded *Sphagnum* peat and a mixture of a perlite and the medium graded *Sphagnum* peat. Containers of two types were packed with the media and allowed to evaporate from saturation. Matric potential was measured automatically using tensiometers during drying.

In both container types, the matric potential of the media was similar down to -10 kPa at each of the three levels measured during drying. Further drying resulted in a large matric potential gradient between the upper and middle levels. During drying, there was also clear shrinkage of the media. When the matric potential at the upper level reached c. -80 kPa, the decrease in height of the media was 5–23 %. The estimated hydraulic conductivity of the media during drying was rather similar. The hydraulic conductivity of the peat-perlite mixture was, however, slightly lower than that of the pure peat media. The hydraulic conductivity decreased linearly on a log-log-scale from c. 10^{-5} to less than 10^{-10} m/s as the matric potential decreased from -3 to -60 kPa. The hydraulic conductivity of the media was comparable to coarse sand at matric potentials below -10 kPa. The decrease in hydraulic conductivity during drying and the possible weakening of soil-root contact due to shrinkage may considerably affect the availability of water to plants.

Turvepohjaisten kasvualustojen vesipotentialiaali ja kyllästymätöntä vedenjohtavuutta mitattiin kuivumisen aikana taimipaakuissa. Edelleen määritettiin rinnakkaisnäytteistä kasvualustojen hiukkaskokojakauma ja vedenpidätyskyky. Kasvualustat olivat karkeaa ja keskikarkeaa vaaleaa rahkaturvetta sekä karkean perliitin ja keskikarkean turpeen seosta. Kasvualustat täytettiin ja tiivistettiin kahteen erityyppiseen paakuun. Kasvualustojen kuivuessa mitattiin niiden matriisipotentialiaali tensiometrisesti kolmelta paakun vertikaaliselta kyllästyskosteudesta alkaen kunnes tensiometriä mittausraja saavutettiin.

Kasvualustojen matriisipotentialiaali oli kuivumisen edetessä lähes sama aina -10 kPa:iin asti kaikilla mittaustasoilla molemmissa käytetyissä paakkutyypeissä. Kuitenkin kuivumisen edetessä muodostui suuri matriisipotentialiaali-gradientti pintakerroksen ja syvemmällä paakussa olevan kasvualustan välille. Kasvualustat myös kutistuivat selvästi kuivumisen aikana. Kasvualustojen kutistuma korkeussuunnassa oli 5–23 %, kun matriisipotentialiaali oli n. -80 kPa pintakerroksessa. Kasvualustojen estimoitu vedenjohtavuus aleni matriisipotentialin alentuessa suhteellisen yhdenmukaisesti. Turpeen ja perliitin seoksen vedenjohtavuus oli kuitenkin hieman alhaisempi kuin puhtailla turvealustoilla. Vedenjohtavuus aleni log-log-asteikolla lineaarisesti n. 10^{-5} :stä alle 10^{-10} :een m/s, kun matriisipotentialiaali

aleni -3:stä -60:een kPa. Kasvualustojen vedenjohtavuus oli verrattavissa hiekkään noin -10 kPa: a alemmilla matriisipotentiaalin arvoilla. Kasvuturpeen kuivuessa vedenjohtavuuden aleneminen sekä kutistumisen mahdollisesti aiheuttama maa-juuri -kontaktin väheneminen voivat heikentää merkittävästi kasvun vedensaataavuutta.

Keywords: matric potential, perlite, shrinkage, substrates, water availability. FDC 181.3 + 114.1

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1 Introduction

The growth medium most commonly used in containerized plant production in the Nordic countries is light, low humified peat. In nurseries, containerized seedlings are under repeated and variable wetting and drying cycles during which water availability to seedlings may markedly change. Under dry conditions, peat has been reported to provide low water availability to tree seedlings (Örlander and Due 1986ab). Water availability and its dependencies upon the properties of various growth media are essential factors in determining correct nursery management practices (e.g. irrigation, shading, ventilation) and, thus, in promoting the growth and quality of seedlings.

Water uptake by a plant root is greatly affected by the force with which water is retained by the growth medium. This force is measured as the water potential of the growth medium. To evaluate water availability to containerized seedlings and the need for irrigation, it is hence important to monitor the water potential (Heiskanen 1993). Water availability is also dependent on the flow rate of water to the root, which is determined by the hydraulic conductivity and the available total water reservoir. Ideally, the hydraulic conductivity should be high enough to replace the water uptake by the root. However, the varia-

tions of water potential and hydraulic conductivity of peat based growth media are poorly known, particularly when used in containers.

The unsaturated hydraulic conductivity of soil depends on the water potential and the physical properties of soil (Hillel 1971). The hydraulic conductivity of mineral soils has been fairly well studied. Conductivity decreases with decreasing water potential and the decrease is generally steeper the coarser the texture. Less is known about the relationships between the unsaturated hydraulic conductivity of various peats and their physical properties. Bartels and Kuntze (1973), Illner and Raasch (1977) and Loxham and Burgardt (1986) give values for some natural peats and Puustjärvi (1991) gives values for a peat growth medium at a few separate matric potentials. However, the hydraulic conductivities of peat and peat based growth media as a function of drying have not been determined.

In this study, the matric potential of peat and a peat-perlite mixture growth medium in containers was measured during drying. The water retention characteristics and unsaturated hydraulic conductivities of the media were also determined. The effect of drying on the hydraulic conductivity of the media and subsequent decreasing water availability to the seedlings are discussed.

2 Materials and methods

Growth media used in this study were 1) Vapo D - a light, low humified, coarse graded *Sphagnum* peat, 2) Vapo E - a medium graded *Sphagnum* peat, and 3) a 1:2 (v/v) mixture of a coarse graded perlite (Nordisk Perlite Corp., Denmark) and Vapo E. Vapo D and Vapo E (Vapo Corp., Finland) are peat media commonly used in Finnish tree nurseries. The particle size distributions of the media were determined from four parallel air dry samples of 300 cm³ using a mechanical sieving machine (Retsch Corp., Germany) and a shaking time of two minutes (Table 1).

The growth media were packed into two types of open-ended polystyrene containers (TK708 and TA710; Lannen Corp., Finland) according to procedures described by Heiskanen (1990). A piece of polyamide netting (mesh size 1 mm) was first placed in the bottom of each container. The TK708 containers are square in cross section and have a volume of 345 cm³. The TA710 containers are circular in cross section and have a volume of 285 cm³. Each medium and container combination were replicated three times. The total number of samples was therefore 18.

Tensiometers, fitted with electrical pressure sensors and connected to an automatic data acquisition system (Heiskanen and Laitinen 1992), were installed at three depths in each container (Fig. 1). The media were then watered abundantly during two days. After the final watering, the media were allowed to freely evaporate in a slowly ventilated fume chamber at 35-40 % relative humidity and 22-25 °C temperature. During the steady, evaporative water flow, the matric potential was recorded at 4 h intervals until the measuring limit of the tensiometers (c. -85 kPa) was achieved (c. 1 month). Evaporation

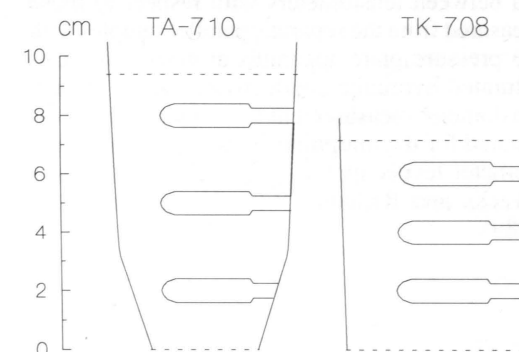


Fig. 1. Container types used and positions of the tensiometers in the containers during the experiment.

from the bottom and sides of the containers was considered to have a negligible effect on the measured matric potential in the growth media. At the end of the measurement period, the shrinkage of the media was measured in both vertical and horizontal direction using a ruler (± 0.5 mm).

Unsaturated hydraulic conductivities were estimated using a method based on that described in detail by Hartge and Horn (1989). First, the desorption water retention characteristics of the growth media were determined from separate, parallel samples (three replicates) using a pressure plate apparatus (Soilmoisture Equipment Corp., USA) and procedures described elsewhere (Heiskanen 1990, Heiskanen and Laitinen 1992). Using the resulting water retention curves (Fig. 2), a water retention value for each calibrated matric potential value measured from the tensiometers (Heiskanen and Laitinen 1992) was then

Table 1. Means and standard deviations of particle size in distribution classes (% m/m) determined from air dry samples (n = 4) of the growth media.

Medium	Fraction, mm				
	< 1	1-5	5-10	10-20	> 20
Vapo D	45.4 \pm 1.3	31.5 \pm 1.9	16.8 \pm 1.1	6.2 \pm 2.41	0.1 \pm 0.13
Vapo E	45.5 \pm 9.6	36.9 \pm 8.3	14.5 \pm 2.4	2.9 \pm 3.13	0.1 \pm 0.08
Perlite	28.8 \pm 4.1	70.8 \pm 3.9	00.4 \pm 0.3	0.0 \pm 0.00	0.0 \pm 0.00

calculated. Shrinkage during water potential measurement was considered not to markedly affect the water retention characteristics of media between tensiometers with respect to those measured from the separate, parallel samples with the pressure plate apparatus at desorption. Unsaturated hydraulic conductivity values at each tensiometer measurement time interval were estimated for the midpoints between the three tensiometer levels applying the following formula (Weeks and Richards 1967, Hartge and Horn 1989).

$$\partial Q/\partial t = A K(\psi_m) (\partial \psi_m/\partial x + \partial \psi_g/\partial x) \quad (1)$$

where

$\partial Q/\partial t$ = flow rate (cm³/h) past a given cross-section (between tensiometers) of medium column,

A = cross-section (cm²),

$K(\psi_m)$ = hydraulic conductivity (cm/h),

$\partial \psi_m/\partial x$ = matric potential gradient (water-cm/cm) at the cross-section,

$\partial \psi_g/\partial x$ = gravitational potential gradient (water-cm/cm) at the cross-section.

Statistical and graphical data analysis was done using SYSTAT-software (SYSTAT 1990ab).

3 Results and discussion

3.1 Matric potential

For the both container types, the matric potentials of the growth media were similar down to -10 kPa at all the three measurement levels (Fig. 3). Further drying, however, resulted in a considerable matric potential gradient between the uppermost and lower tensiometer levels. When the matric potential at the middle level was -20...-30 kPa, it was about -80 kPa at the uppermost level. At the lowest measurement level, the matric potential was little higher than at the middle level. When the potential at the middle level lowered to -40...-60 kPa, it was -30...-40 kPa at the lowermost level in TA710 containers. Because of the higher surface area to height ratio, the media dried faster in the TK708 containers than in TA710 containers. In addition, differences in seedling transpiration mainly affect the matric potential and water availability in the con-

tainer. Therefore, at high evapotranspiration rates, it is likely that the need for irrigation during seedling production is greater when using TK708 containers than when using TA710.

Under high evaporative conditions, water availability (see Örländer and Due 1986ab) may also start to rapidly decrease even though the bulk matric potential would be as high as > -20 kPa. If the matric potential at the peat surface is lower than -80 kPa, watering may become difficult due to the water repellency of the dry peat surface. Hence, a water deficit may rapidly follow if the peat cannot absorb sufficient irrigation water to compensate for the water loss.

All the media clearly shrank during drying. When the matric potential at the surface level in the TK708 containers had reached about -80 kPa, the decrease in height of the Vapo D, Vapo E and the peat-perlite mixture was 18-23, 15-20 and 10-15 %, respectively. With the TA710 con-

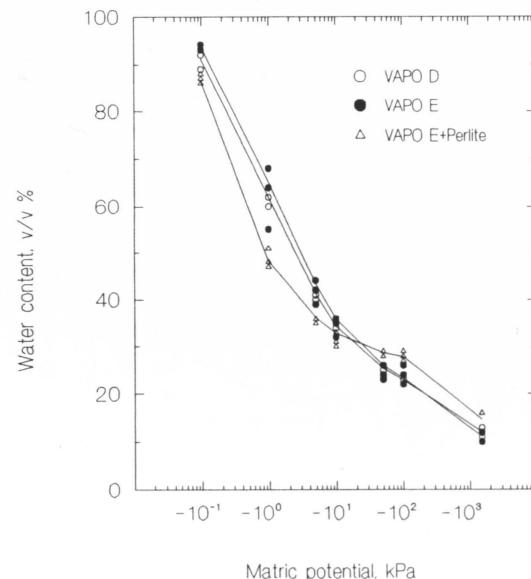


Fig. 2. Water retention characteristics of the growth media.

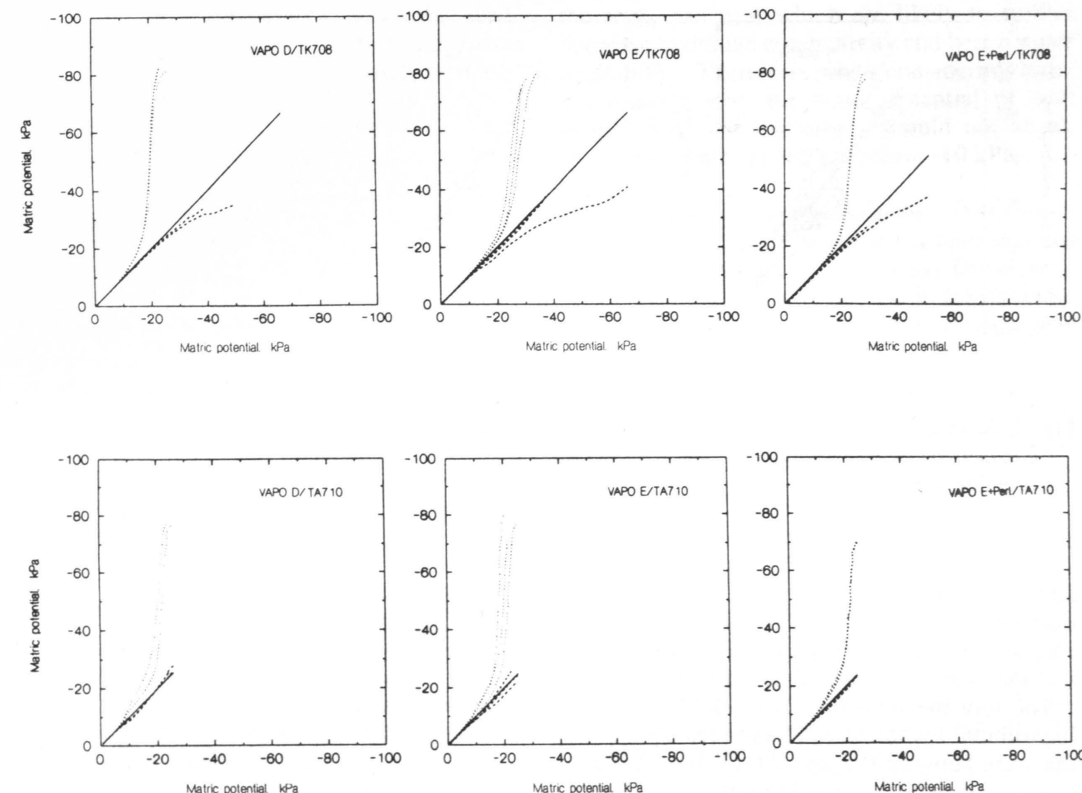


Fig. 3. Matric potential of the growth media at different levels in the containers during drying. Matric potentials are in respect to the matric potential in the middle tensiometer level. (Tensiometer levels: dotted line = upper, solid line = middle, broken line = lower).

tainers, the shrinkage was less; 7-11, 5-7 and 5-10 %, respectively. The mean shrinkage in the horizontal direction was between 4-9 % in all the media.

3.2 Hydraulic conductivity

The particle size distribution and water retention characteristics of both the pure peat media, Vapo D and Vapo E, were rather similar (Table 1, Fig. 2). The water retention characteristics are comparable to those given for medium textured peat media (Heiskanen 1990). The perlite was dominated by particles of 1 to 5 mm diameter and hence the peat-perlite mixture was expected to contain a relatively high proportion of coarse pores. This would explain that the peat-perlite mixture released more water than the pure peats when the matric potential was lowered from sat-

uration to -1 kPa. However, the peat-perlite mixture also retained more water than the peats at potentials < -50 kPa. This is likely to be because perlite contained some very fine particles.

The estimated unsaturated hydraulic conductivities of all three media decreased in a rather uniform way during drying (Fig. 4, Table 2). Hydraulic conductivity decreased almost linearly on a log-log-scale from about 10⁻⁵ to less than 10⁻¹⁰ m/s as the matric potential decreased from -3 to -60 kPa. The pure peat media had very similar hydraulic conductivity. The peat-perlite mixture had, however, somewhat lower hydraulic conductivity, which was due to the very low hydraulic conductivity of perlite (Jackson 1974). For example at -10 and -50 kPa, the average hydraulic conductivity of the peat media was c. 1 × 10⁻⁷ and 2 × 10⁻¹⁰ m/s, respectively, while that of the mixture was 3 × 10⁻⁸ and 7 × 10⁻¹¹ m/s, respectively. Hence, the coarse perlite as an

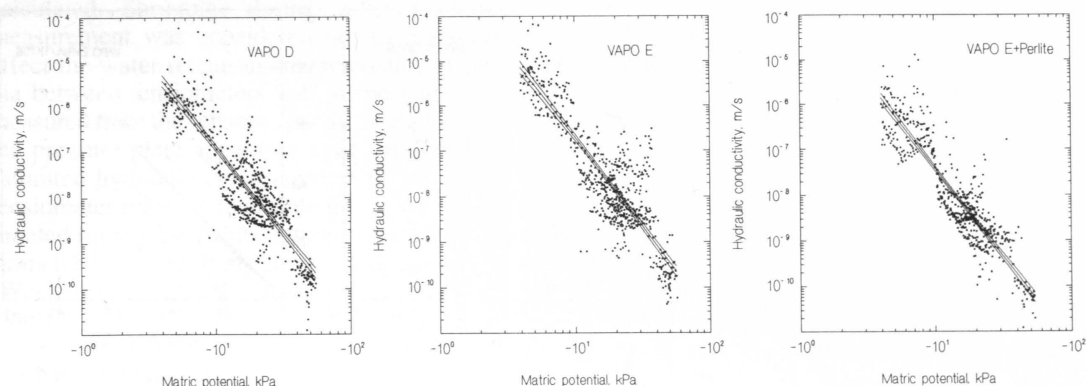


Fig. 4. Scatterplots, fitted regression lines and their 95 % confidence intervals for unsaturated hydraulic conductivity of the growth media during drying. Data were combined from the results of the samples in both container types used.

additive to the peat lowered the hydraulic conductivity compared with that of the pure peat media. The container type was found not to affect the hydraulic conductivity values.

The root mean square errors (RMSE) of the logarithmic hydraulic conductivities of the media were between 0.5 and 0.6 (Table 2). Thus, average deviation in the logarithmic hydraulic conductivity about the regression lines was about an half an order of magnitude (Fig. 4). The deviations of the values from linearity were likely due to the natural heterogeneity of the medium materials and also, possibly, partly to methodological reasons. The water retention characteristics determined from the parallel samples may differ somewhat from the actual characteristics of the media in the containers during drying, for example due to variations in shrinkage and medium materials. In addition, deviations from the stationary water flow during the measurement due to possibly varying evaporation rate and nonisothermal water flow may have caused slight inaccuracy to the hydraulic conductivity values.

The estimated hydraulic conductivity values are relatively similar to those reported in the literature, despite the different measurement techniques used. Bartels and Kuntze (1973) reported the hydraulic conductivity of an undisturbed, low humified (H2-3) peat to decrease from 1.4×10^{-8} to 2.3×10^{-11} m/s when the matric potential decreased from -10 to -100 kPa. Loxham and Burghardt (1986) studied peats from several peatlands and they found a *Sphagnum* bog peat (H2-3) to have the hydraulic conductivity of about 10^{-7} , 10^{-8} and 10^{-9} – 10^{-10} m/s at -3, -10 and -32

Table 2. Parameters for the regression equations $\log_{10}(y) = a + b \log_{10}|x|$, i.e. ($y = 10^a |x|^b$) showing the relationships between the hydraulic conductivity (y , m/s) and matric potential (x , kPa) of the growth media. Root mean square errors (RMSE i.e. standard errors of the estimates), regression coefficients (r) and their significances (p) are for $\log_{10}(y)$.

Medium	a	b	RMSE	r	n	p
Vapo D	-3.184	-3.721	0.58	0.88	628	< 0.0005
Vapo E	-2.772	-3.934	0.61	0.87	674	< 0.0005
Vapo E + Perlite	-3.549	-3.863	0.51	0.90	597	< 0.0005

kPa, respectively. Rather similar results were also obtained for low humified (H2-4) *Carex* and *Phragmites* peats by Illner and Raasch (1977). According to Puustjärvi (1991), the hydraulic conductivity of a light *Sphagnum* peat growth medium is 2.2×10^{-7} m/s and 5.5×10^{-8} m/s when water content is 50 and 35 %, respectively. These water contents correspond to matric potentials of about -1 and -5...-10 kPa, respectively. The hydraulic conductivity of the studied growth media is comparable to coarse sand at matric potentials < -10 kPa (Bartels and Kuntze 1973, Scheffer and Schachtschabel 1989). At matric potentials > -10 kPa, the hydraulic conductivity of the media is slightly higher than that of coarse sand.

The water availability of a low humified, fine

graded peat growth medium to Scots pine seedlings (1-year-old) has been reported to decrease markedly when the matric potential decreases beginning from about -10 kPa (Örlander and Due 1986b). This indicates that either the hydraulic conductivity diminishes or the soil-root contact area becomes less, or both. In this study, the hydraulic conductivity of coarse to medium graded peat growth medium was shown to decrease steeply (logarithmically) in relation to decreasing matric potential. Thus, at matric potentials < -10 kPa, the hydraulic conductivity of peat was indeed low. Shrinkage during drying may result in the formation of air gaps between

the roots and peat which are likely to further decrease hydraulic conductivity and hence water availability. Therefore, when considering nursery management, the water potential of peat growth media in containers should not be allowed to frequently fall far below -10 kPa.

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Total of 17 references