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Investigations of Physical Properties of Substrates

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Summary

Thirteen commercially available substrates of different composition are described concerning particle density, total pore space, water as well as air capacity, available water, particle size distribution. Particle density, total pore space and water and air capacity were determined according to DIN EN 13039 and 13041 (2000), available water according to GABRIELS and VERDONCK (1992). Particle size distribution was carried out according to RHP (WEVER and VERHAGEN 1995).

Particle densities were between 1,69 and 2,19 [kg L^{-1}] depending on the composition. Three from thirteen substrates had an air capacity smaller than 10 % [v/v], three higher than 15 % [v/v], seven ranged between 10 and 15 % [v/v]. The amount of available water was smaller than 30 % [v/v] for one substrate, between 35 and 40 % [v/v] for four substrates and between 40 and 48 % [v/v] for eight substrates. Most particles (63–93 %) occurred in the fractions <4,0 mm. Within this fraction in most cases most particles were smaller than 1 mm.

There is a trend of decreasing air capacity with increasing amount of available water, but r^2 is very small (0,48). The same is true for the correlation between particles <1 mm and air capacity (r^2=0,46). Reasons for this are discussed.

Zusammenfassung

Untersuchungen physikalischer Substrateigenschaften Für 13 im Handel erhältliche Kultursubstrate mit unterschiedlicher Zusammensetzung wurden Partikeldichte, Gesamtporenvolumen, Wasser- und Luftkapazität, verfügbares Wasser und die Korngrößenverteilung ermittelt. Partikeldichte, Gesamtporenvolumen, Wasser- und Luftkapazität wurden nach DIN EN 13039 bzw. 13041 (2000), das verfügbare Wasser nach GABRIELS und VERDONCK (1992) bestimmt. Die Korngrößenverteilung wurde nach der Methode der RHP (WEVER and VERHAGEN 1995) gemessen.

Die Partikeldichten lagen – in Abhängigkeit von der Zusammensetzung der Substrate – zwischen 1,69 und 2,19 [kg L^{-1}]. Drei der 13 Substrate wiesen eine Luftkapazität unter 10 % [v/v] auf, für drei Substrate lag sie über 15 % [v/v], für sieben Substrate zwischen 10 und 15 % [v/v]. Ein Substrat hatte weniger als 30 % [v/v] verfügbares Wasser, für vier Substrate lag der Wert zwischen 35 und 40 % [v/v], für acht Substrate zwischen 40 und 48 % [v/v]. Die meisten Partikel (63–93 %) kamen in dem Korngrößenbereich <4 mm vor. Innerhalb dieser Fraktion lag bei den meisten Substraten der größte Anteil bei einem Korndurchmesser <1 mm.

Die Luftkapazität nimmt mit steigendem Anteil an verfügbarem Wasser tendenziell ab, doch das Bestimmtheitsmaß ist sehr klein (r^2=0,48). Das trifft auch für den Zusammenhang zwischen Luftkapazität und Anteil an Partikeln <1 mm zu (r^2=0,46). Gründe dafür werden diskutiert.

Key words. air capacity – available water – particle density – particle size – total pore space – water capacity

Introduction

While chemical properties of substrates are well known this is not the case for the physical ones. The determination takes time and the results are often not easily interpreted. Consequently only few results are available. Furthermore, even less is known about how physical properties of substrates are connected. This might be of interest for the substrate producer as well as for the grower. The amount of available water determines the frequency of irrigation and the amount of water per irrigation event. The air capacity is important for crops sensible to lack of air as well as for crops with a long growth period, since it tends to decrease with time.

Hence, an attempt is made to describe and to evaluate physical properties of 13 commercially available substrates.

Materials and Methods

13 commercially available substrates were investigated concerning their physical properties. The main components of these substrates were white peat (different grades) and black peat, followed by peat fibres, clay, composted bark, cocofibres, and rice hulls (Table 1).

The determination of the total pore space, water and air capacity was carried out according to DIN EN 13040 (sample preparation) and 13041. In DIN EN 13041 the water capacity is defined by the water content (%, v/v) measured after drainage at a negative pressure head of –10 hPa. Air capacity is calculated from the difference between total pore space and water capacity. The measurements were carried out with four replications. For the calculation of the total pore space

Table 1. Constituents of the investigated substrates.

Substrate	Constituents
1	70 % white peat (fine), 30 % clay
2	75 % white peat (medium), 25 % clay
3	70 % white peat (medium), 30 % clay
4	white peat and granular clay
5	white peat and granular clay
6	70 % white peat, 15 % clay, 15 % cocofibres
7	33 % white peat, 37 % composted bark, 15 % clay, 15 % rice hulls
8	80 % black peat, 20 % white peat (fine)
9	50 % white peat (medium) and 50 % black peat
10	50 % white peat (fine) and 50 % black peat
11	33 % white peat (medium), 33 % black peat, 33 % peat fibres
12	white peat (fine)
13	white peat (medium)

Table 2. Particle density, total pore space, water and air capacity, available water and particles <4 mm and <1 mm of 13 substrates (In brackets: standard deviation).

Substrate	Particle density [kg L^{-1}]	Total pore space [%. v/v]	Water capacity [%. v/v]	Air capacity [%. v/v]	Available water [%. v/v]	Particles <4 mm [%. m/m]	Particles <1 mm [%. m/m]
1	2.11	87.9 (1.1)	79.9 (2.2)	8.0	43.0	81.0	40.4 (2.6)
2	2.10	87.0 (1.6)	77.9 (4.2)	9.1	40.0	87.9	61.4 (5.8)
3	2.19	88.5 (0.1)	76.5 (1.9)	12.1	41.5	77.9	34.6 (6.3)
4	1.94	90.6 (0.7)	78.8 (1.1)	11.8	45.1	83.1	57.2 (3.0)
5	2.06	91.1 (0.5)	77.7 (0.5)	13.4	47.1	93.1	55.9 (1.9)
6	2.02	90.1 (0.8)	68.1 (1.6)	22.0	35.5	70.4	38.1 (6.5)
7	1.99	88.0 (0.8)	56.5 (0.7)	31.4	25.6	62.6	27.4 (5.2)
8	1.72	90.5 (0.2)	83.5 (2.7)	7.0	36.4	92.2	69.3 (2.7)
9	1.72	92.7 (0.3)	79.6 (0.7)	13.1	45.7	82.7	60.6 (8.1)
10	1.70	92.5 (0.3	82.1 (0.2)	10.4	47.5	93.2	68.6 (5.2)
11	1.71	92.8 (0.8)	77.0 (3.7)	15.8	38.6	70.7	50.5 (4.7)
12	1.69	92.4 (0.3)	77.9 (1.8)	14.5	45.2	88.1	52.1 (2.9)
13	1.70	94.3 (0.4)	79.7 (4.1)	14.6	44.6	69.7	42.6 (4.3)

it is necessary to know the particle density, which is calculated from the contents of organic matter and ash. These were determined with the method described in DIN EN 13039 with two replications. The available water was measured according to the ISHS-method (GABRIELS and VERDONCK 1992) as the difference between the water content [%, v/v] at –10 hPa and –100 hPa. Due to the large number of different samples only two replications were carried out.

The particle size distribution was determined by sieving according to RHP (WEVER and VERHAGEN 1995). The sieving equipment consists of 6 sieves with mesh diameters of 1,0 mm, 2,0 mm, 4,0 mm, 8,0 mm, 16,0 mm and 31,5 mm. The sieving was carried out with three pre-treatments: "air dry" (leaving the substrate for 48 hours in the greenhouse in a layer of 4–5 cm), "oven dry" (leaving the substrate for 48 hours at 25 °C in the oven and stirring the material carefully three times a day), "moist" (the substrate was used directly from the bag). The determinations were carried out with three replications.

Results

The results for the particle density, total pore space, water and air capacity, available water, and particle sizes are given in Table 2.

Substrates containing clay have a particle density > 1,90 [kg L^{-1}]. Within this group the particle density – though not consistent – increases with increasing clay content. Lower total pore spaces (87–91 % [v/v]) are measured for substrates containing clay (no. 1–7) and for the substrate with a high amount of black peat (no.

8). Substrates containing only peat and no other components (except no. 8) have total pore spaces of 92 to 94 % [v/v] (no. 9–13).

11 from 13 substrates have water capacities between 77 and 82 % [v/v]. The lowest water capacity of 57 % [v/v] is found for the substrate containing beside 33 % white peat composted bark, rice hulls and clay (no. 7). Addition of 15 % cocofibre results also in a comparatively low water capacity of 68 % [v/v] (no. 6).

The substrate containing composted bark and rice hulls has only 26 % [v/v] available water (no. 7). For four substrates (no. 2, 6, 8, 11) the available water is between 35 and 40 % [v/v]. Here it is interesting to note that for the substrates containing peat fibres resp. cocofibres (no. 6 and 11) the low amount of available water is combined with a high air capacity, while this is not the case for the substrate containing 80 % black peat (no. 8). For the other substrates the amount of available water lies between 42 and 48 % [v/v]. While a low water capacity coincides with little available water (no. 6 and 7), a high water capacity is not always combined with much available water. Substrate no. 8 has a water capacity of 84 % [v/v], but only 36 % [v/v] available water. For all substrates investigated the correlation between water capacity and available water is small (r^2=0,64, without figure).

The lowest air capacity is determined for the substrate with 80 % black peat, followed by two of the substrates containing 30 %, resp. 25 % clay. These substrates have an air capacity smaller than 10 % [v/v]. Air capacities between 10 and 16 % [v/v] are measured for substrates containing peat (but not more than 50 % black peat) and no further components (no. 9–13) and for 3 substrates with clay (no. 3–5). Two of them contain clay granules (no. 4, 5). The highest air capacities are measured for substrates containing, among others, cocofibres and rice hulls (no. 6, 7). Fig. 1 shows that an increase in air capacity is at the cost of available water. But the correlation is small (r^2=0,48).

Results for sieving given here refer to the treatment "oven-dry". The results of sieving showed that particles >16 mm do not play a role, with the exception of substrate 7 which had 9,7 % [m/m] in the fraction 16,0–31,5 mm. This is the substrate with the highest air capacity. Three other substrates have between 1 and 2 % particles in this fraction (4, 6, 13, not shown here). Most particles occur in the fractions 4,0–2,0 mm, 2,0–1,0 mm and <1 mm. These are together between 63 % for substrate 7 and 93 % for substrate 5 and 10. From this the biggest part is in the fraction <1 mm (Table 2).

Fig. 2 shows the relation between particles <1 mm and the air capacity. It is obvious that there is a trend, but a poor correlation (r^2=0,46). r^2 for the treatments "air dry" and "moist" were even smaller. When omitting the three substrates containing 25 and 30 % clay r^2 increases to 0,86 (without figure).

Discussion

Generally spoken a substrate can never contain too little water but only too little air. This means that much available water is desirable as long as there is enough air at the same time. Concerning threshold values of "enough air" there is much controversy in the literature. They range from at least 6–10 to 30–40 % [v/v] (i.e. AENDEKERK 1983; PENNINGSFELD 1988; SCHIE 1999). For VERDONCK et al. (1983) 20–30 % [v/v] are normal. One reason for various threshold values, but not the only one, are different methods how physical properties are determined. Furthermore, results with some ornamental plants show that these plants grew well at very low air capacities smaller than 10 %. (SCHARPF 1997). Since "enough air" is mainly a matter of transport of CO_2 out of the substrate and O_2 into the substrate, the diffusion rate of these gases might be a better indicator for the supply with air. Accordingly, ALLAIRE-LEUNG et al. (1999) and CARON and NKON-

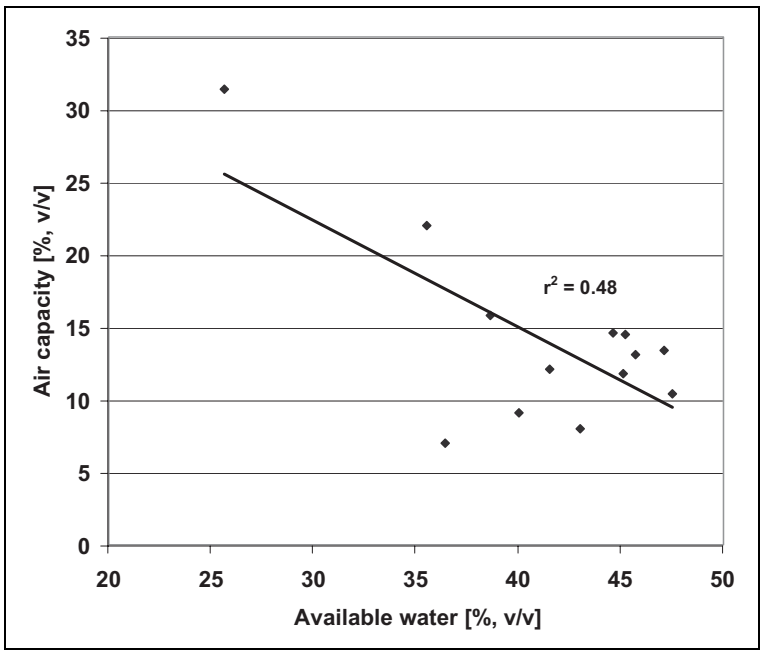


Fig. 1. Air capacity in relation to available water

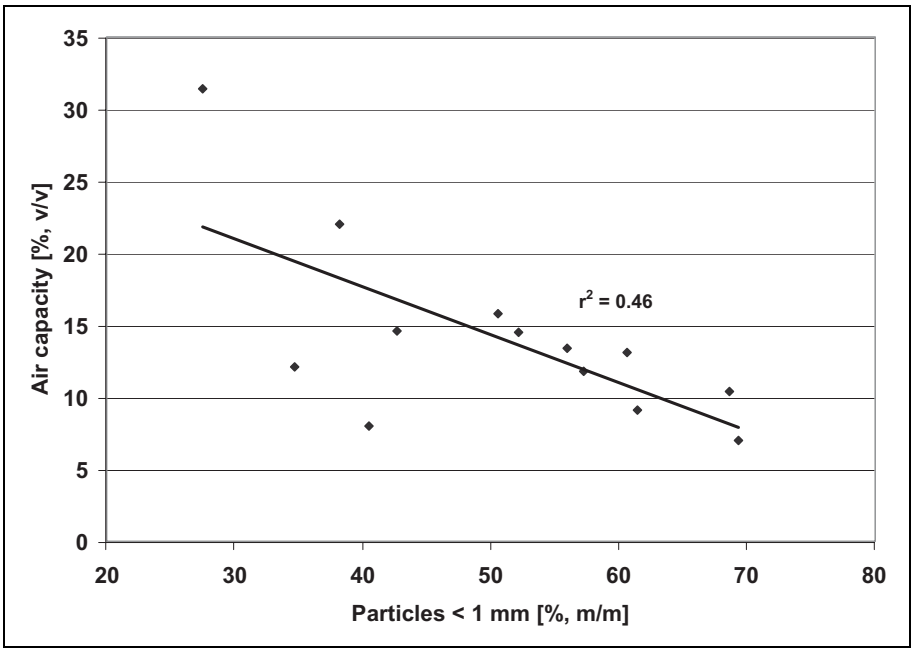


Fig. 2. Air capacity in relation to particles <1 mm.

GOLO (1999) showed that plant growth is better correlated with the diffusion rate than with air capacity. However, substrate properties and qualities are still described in terms of water capacity, air capacity, and available water.

Working with these parameters for the assessment of an "ideal substrate" it is interesting to know how they are related. Furthermore, since their determination takes much time, it is useful to check if there is a correlation with a more easily to determine parameter like the particle size distribution.

Fig. 1 shows that an increase in air capacity is at the cost of available water, but the correlation is very small (r^2=0,48). Only for substrates with a very high air capacity of more than 15 % [v/v] the amount of available water is clearly decreasing. In the range of 10–15 % air capacity [v/v] the amount of available water is between 43 and 48 % [v/v], in most cases about 45 % [v/v]. This means that it is possible to produce substrates with both: enough available water and at the same time a "reasonable" amount of air (10–15 % [v/v]), being aware that this threshold value for air capacity is not unequivocal. Between 5 and 10 % air capacity [v/v] the available water varies between 36 and 43 % [v/v]. From this little air capacity does not necessarily mean much available water, on the contrary, most substrates within the group 10–15 % [v/v] air capacity contain more than 43 % [v/v] available water. The lowest amount of air as well as available water is found in the substrate containing 80 % black and 20 % white peat. The two other substrates in this group contain beside white peat 25 resp. 30 % clay.

From Tables 1 and 2 it is to be seen that the substrates with 10–15 % [v/v] air capacity and about 45 % [v/v] available water contain mainly white peat (more than 33 %) and not more than 50 % black peat (no. 9, 10, 12, 13) or white peat and clay (no. 3, 4, 5). Substrates 4 and 5 contain clay as granules, the amount is not known. It is not surprising that substrates containing mainly white peat constitute this group, since white peat is known to offer favourable conditions concerning water as well as air. So, instead of a correlation between available water and air capacity there seems to be more a grouping, determined by the composition of the substrates.

Due to the method for the determination of the available water the lower limit is set at –100 hPa. Of course, plant and climatic conditions influence the lower limit (i.e. SPOMER and LANGHANS 1975; BERNIER et al. 1995). Hence, similar to air capacity, this threshold must not be generalized. Many substrates contain considerable amounts of water at matric potentials <–100 hPa, which does not appear working with the lower limit of –100 hPa.

Looking for a correlation with the particle size distribution was encouraged by results from the literature. SCHARPF (1997) found that for white peat water capacity increased when the amount of particles smaller than 1 mm increased. An increase in water capacity was thought to be equivalent to a decrease in air capacity, hence air capacity should decrease with an increasing amount of particles smaller than 1 mm. LIMBERS and REHME (1997) found for two white peat samples with each fine, medium and coarse structure a linear decrease of the air capacity with an increase in particles smaller than 0,2 mm. VERHAGEN (1997) calculated the air capacity for a milled and pre-sieved peat from the amount of particles smaller than 1 mm. When he used a peat which was not pre-sieved, the correlation between air capacity and particles smaller than 1 mm could not be found.

The results shown here do not have a close correlation between air capacity and particles smaller than 1 mm and seem to contradict the former ones. The results from the literature were obtained with peat alone, in part pre-sieved, probably with star-sieves, which are used by substrate producers (SCHMILEWSKI 1992). In contrast to this, the own investigations were carried out with a wide range of non pre-sieved substrates and

mixtures, some of them containing three or four components. In agreement with these results SCHARPF (1997) also stated that the close correlation between water capacity (and hence air capacity) and particles smaller than 1 mm could not be confirmed for substrate mixtures. From the data presented here it seems that specially a higher amount of clay (25–30 %) is the cause for the poor correlation, since omitting these three substrates r^2 increases to 0,86. However, too few substrates of this composition were used here to assure this hypothesis.

Also from another point of view a small correlation between particle size and air capacity (and other physical properties) is not surprising. Organic particles differ extremely in particle shape and firmness of the material. Although the sieving process is defined, particles of different materials will be stressed to a different degree, which will influence the particle size for instance by abrasion. This might be a reason why good correlations are found for one single material (peat), but not when including several materials. Additionally the diameter of the particles determined by sieving is not a real one, but a diameter, where the particle is in such a position in which it can pass the meshes of the sieve. This position changes with the motion of the sieves and is purely by chance. Especially irregular shaped particles, which are typical of organic materials, might show another diameter when hitting on the meshes of the sieve in another position. Probably pre-sieving with star-sieves might have reduced not only the amount of possible sizes but also of possible shapes.

In addition it cannot be excluded that there are differences even between different bags of the same brand of a substrate. A white peat from two bags of the same brand showed differences in the air capacity of about 15 % [v/v] (AGNER 2003).

Conclusions

Physical properties like available water and air capacity of substrates with different composition are poorly correlated with each other. Instead, there seems to be a grouping, which is mainly determined by the composition of the substrates. From this the grower cannot generally derive one property from the other.

From the evaluation of the data presented here in combination with those from the literature it also has to be concluded that the particle size distribution cannot be used generally to derive data for the air capacity of substrates. It seems that this is possible only within relatively homogenous materials concerning firmness and shape of the particles.

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