The physical properties of peat: a key factor for modern growing media

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SUMMARY

This article identifies criteria for assessing the physical properties (water retention characteristics, wettability and physical stability) of growing media which influence the availability of air and water to plant roots. The various materials that are currently in use are assessed for these properties. The analysis of physical properties indicates that weakly decomposed (H1–H5, generally referred to as white) *Sphagnum* peat is still indispensable for soil-less horticulture. Whilst a number of materials can be used as peat additives, especially to improve aeration, no alternative products with equivalent physical properties are available at present.

KEY WORDS: air volume content, water retention, wettability.

INTRODUCTION

Soil-less cultivation systems have low resistance to change in temperature, water content and solute concentrations because of the limited volume of growing medium available to roots within the pot or container. The growing media used must, nonetheless, provide (just as does soil *in-situ*) physical functions such as anchoring of the plant and sufficient supplies of solutes, water and oxygen. Various materials, including peat, are used for this purpose. The aim of this article is to identify and illustrate the principal physical properties of growing media that influence the availability of water and oxygen, and to assess the different materials for these properties.

WATER RETENTION CHARACTERISTICS

The relevant physical attributes of a growing medium are primarily those that influence its ability to provide water to the root system without cutting off the oxygen supply. The analysis of these properties is based on the volumetric distribution of water and air in the growing medium in relation to the water potential; that is, the water retention energy in the growing medium.

Determination method

Since the physical properties of growing media are largely influenced by how the materials are packed, the materials were prepared following the European standard procedure NF EN 13041 (2000). Two PVC cylinders (diameter: 14 cm; height: 14 cm) were manually filled with growing medium, slowly wetted (30 minutes) from the bottom, saturated for 24 hours and then allowed to equilibrate to a water potential of -3.2 kPa over 48 hours. The cylinders were emptied, the materials homogenised and other smaller PVC cylinders (diameter: 10 cm; height: 5 cm; volume = 393 cm^3) were filled without packing and slowly re-wetted from the bottom for 24 hours. Four replications of each substrate were used for this experiment, and standard deviations are generally no more than 2%.

Water retention properties were then determined using the hydrostatic method initially described by van Djik & Boekel (1965), by placing the materials in small cylinders on a tension table to drain at various water potentials, from -1 kPa to -10 kPa.

Physical characteristics

From water retention curves, the following properties are taken into account (Figure 1):

(1) total pore space, which is the total void volume (available to water and/or air) as a proportion of the total volume of the growing medium;

(2) air volume content, also called air-filled porosity, which is the volumetric proportion of the water contained at saturation (water potential = 0 kPa) in the coarsest pores and therefore readily released and replaced by air at water potentials between 0 and -1 kPa;

(3) water availability, which is the volumetric proportion of pore water retained in the growing medium by forces compatible with root extraction capability (defined for the range of water potential from -1 kPa to -10 kPa); and

(4) water buffering capacity, defined as the volumetric proportion of water released by the growing medium between -5 and -10 kPa, enabling physiological adaptation of the plant to the changing water potential.

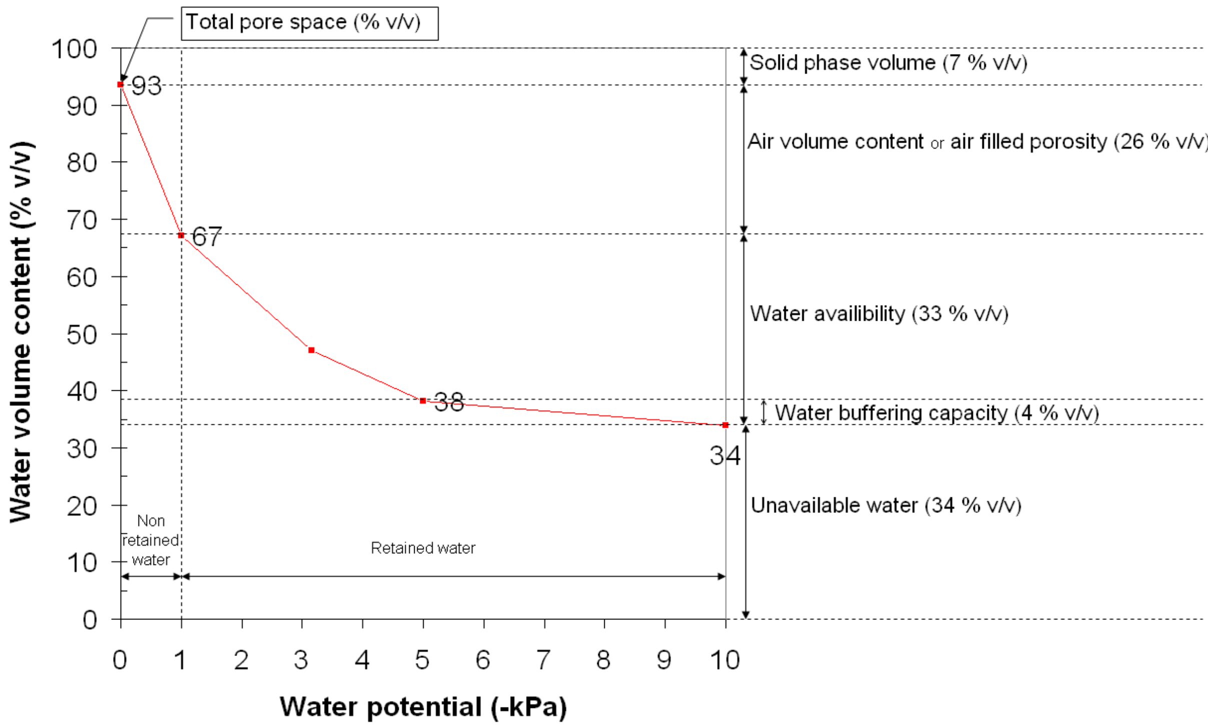


Figure 1. Key features of an example water retention curve.

Water retention characteristics of different types of peat

From the physical point of view, different types of peat can be distinguished according to their botanical origin, degree of decomposition and particle size distribution. For the same degree of decomposition, *Sphagnum* peats will generally have more favourable physical properties than other types (herbaceous etc., which often have higher ash content), implying a substantial degree of water retention, but to the detriment of aeration. In comparison to white *Sphagnum* peats, the more decomposed black *Sphagnum* peats (H6–H10, but highly decomposed - H9–H10 - peats are not used in practice) have less favourable structure. This results from fibre degradation, which gives a much finer material texture, so that these peats often present inadequate aeration and deterioration of the initial properties (irreversible loss of volume) during use (Figure 2).

Peats may also be distinguished on the basis of particle size distribution (granulometry), which imparts greater retention or aeration capacity depending on whether the material is, respectively, fine or coarse (Figure 3). Differences in granulometry may result from several factors. First, degree of decomposition (a function of age) may differ from one white peat to another (e.g. marketed Baltic peats are generally younger than Irish peats). Secondly, the extraction method (e.g. block cutting *versus* milling) and the drying process are extremely important in terms of how much of the original structure of the peat is retained. Thirdly, structure is also altered by the processes involved in manufacturing growing media (hammer-milling, calibration, sieving *etc*.).

Classification of growing media

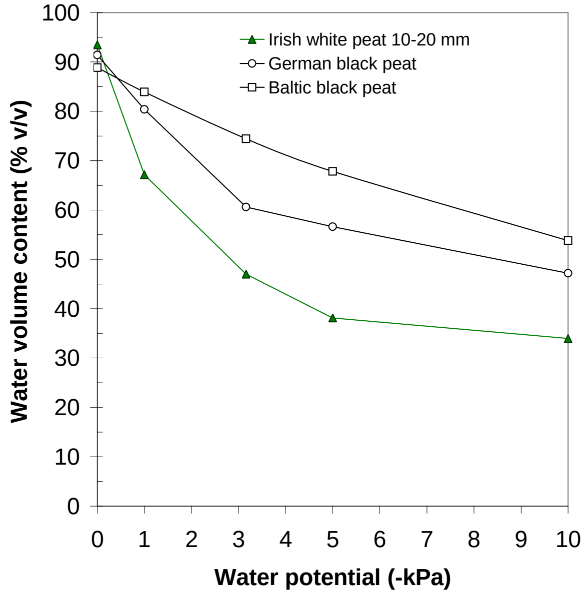
For horticultural use, four types of growing medium can be distinguished on the basis of their water retention curves (Rivière *et al.* 1990) (Figure 4). These are:

Type I: aerated growing media (air volume content > 20 % v/v) with high water availability (> 25 % v/v) and high water buffering capacity. These properties are exhibited by some *Sphagnum* peats, but are most often achieved by mixing several different materials. This is the "ideal" type because it has the most flexible irrigation requirements and is thus the least restrictive in terms of water management.

Type II: less aerated growing media with average to high water availability. Due to their finer pores and consequently higher water retention than Type I materials, the major disadvantage is the potential risk of cutting off the oxygen supply to the root system. Black peats provide the main examples. Non-*Sphagnum* peats are often very similar to Type II growing media.

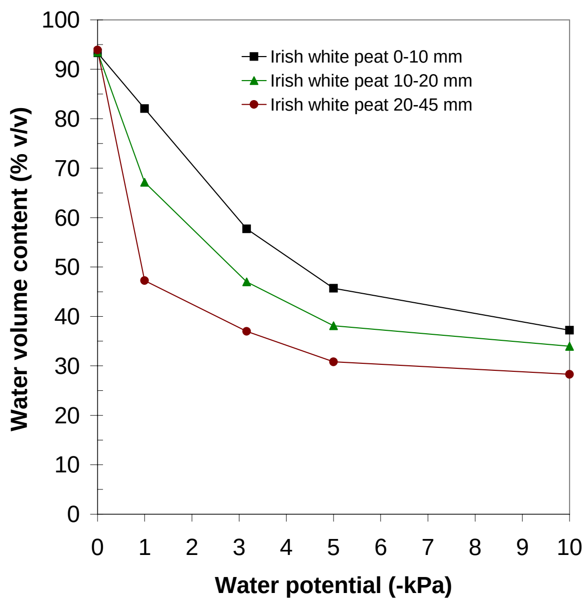
Type III: highly aerated growing media with low water availability. If used alone, the low water availability would necessitate too-frequent low-dose irrigation. Accordingly, this type of medium is used mainly for mixing with Type I and Type II media in order to improve aeration. Many organic and mineral products present these physical characteristics; for example bark (fresh or composted), wood fibre, perlite and pozzolan (pumice);

Type IV: aerated growing media with high water availability but whose water reserve is rapidly depleted (low water buffering capacity). This



	Air volume content (% v/v)	Available water (% v/v)	Water buffering capacity (% v/v)
Irish white peat 10-20 mm	26	33	**4**
German black peat	**11**	33	9
Baltic black peat	**5**	30	14

Figure 2. Examples of retention curves of different types of peat at various degrees of decomposition, and consequences in terms of physical characteristics.



	Air volume content (% v/v)	Available water (% v/v)	Water buffering capacity (% v/v)
Irish white peat 0-10 mm	**11**	45	8
Irish white peat 10-20 mm	26	33	**4**
Irish white peat 20-45 mm	47	**19**	**3**

Figure 3. Examples of water retention curves of white *Sphagnum* peat with different particle size distributions.

category includes materials with fibrous structures, such as mineral wool and some wood fibres, in which there is low or no water retention within the fibres and water is stored at the contact points between them. One consequence of the low water retention energy is highly irregular distribution of water, giving a much higher air:water ratio at the top than at the bottom of the container. Despite the high water availability, this material requires permanent irrigation monitoring because of its low water buffering capacity.

Most of the materials used for growing media are chosen for either their aeration or their water retention properties. Materials that have favourable attributes in both of these respects (Type I) are rare. Thus, the base material for horticulture is generally white *Sphagnum* peat (Figure 4).

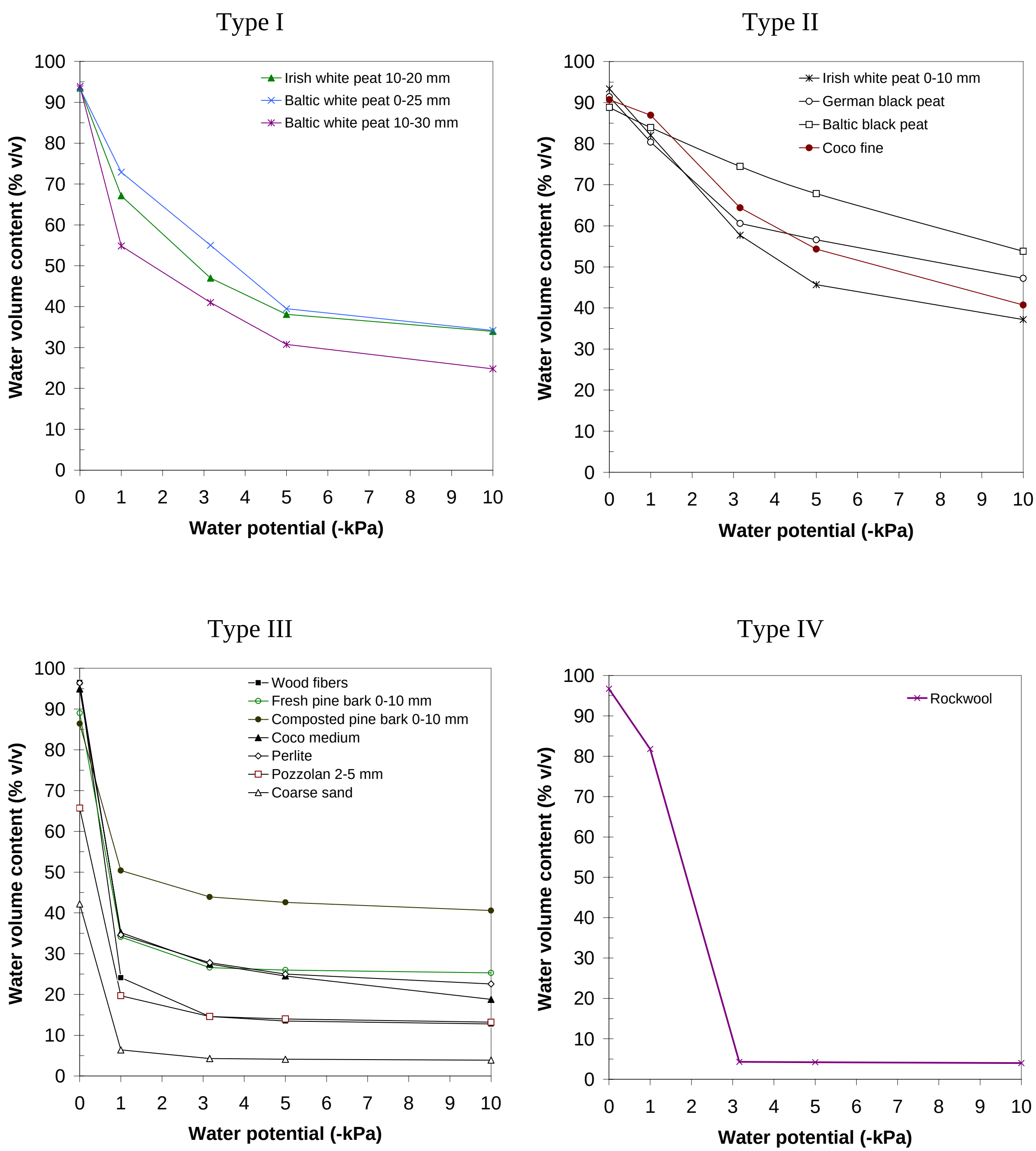


Figure 4. Examples of water retention curves for different materials used as growing media.

WETTABILITY

The wettability of a material describes its ability to re-wet itself once it has dried out. This is a particularly important property of horticultural growing media because it determines the effectiveness of water uptake by the medium - and therefore by the plant - following water removal by evaporation or through roots and evapotranspiration. Wettability is often expressed in terms of qualitative attributes such as the Water Drop Penetration Time (WDPT) and can be quantified in terms of the contact angle of a drop of water placed on a solid surface (Michel *et al.* 2001, Michel 2009) (Figure 5).

In general, a material is considered to be hydrophilic (or wettable, i.e. having a strong affinity for water) when the contact angle is less than 90° and hydrophobic (or water repellent, i.e. having little or no affinity for water) when the contact angle is greater than 90°. Mineral materials are characteristically hydrophilic, whereas most of the organic materials used as growing medium constituents, with the possible exception of coir (coco), are likely to acquire a hydrophobic character if over-dried. Black *Sphagnum* peats generally acquire a more pronounced hydrophobic character than white peats if they dry out naturally (Michel *et al.* 2001). This is obviously a major constraint and must be taken into account for irrigation management. Amongst the possible reasons for acquiring a hydrophobic character are the actual processes used to make growing media (involving partial drying of the materials), as well as errors in irrigation management and monitoring.

PHYSICAL STABILITY

In addition to having suitable physical characteristics initially, it is also essential that growing media maintain these properties during plant growth. Among the main criteria for physical instability, we can include the lack of maturity (i.e. propensity for rapid decomposition) of some organic materials that are used as growing media (particularly composted materials); as well as cycles of alternating drying and wetting, which affect the growing medium during plant growth and may also lead to the problems of hydrophobicity mentioned above. We can distinguish three major categories of materials on the basis of physical stability:

(1) physically stable rigid materials in which drying/wetting cycles do not lead to changes in total volume or in the organisation of the solid phase or pore space (e.g. bark);

(2) physically unstable elastic materials in which cycles of alternating drying and wetting lead to shrinkage (during drying) and swelling (during re-wetting) but with irreversible loss of total volume and considerable modification of the pore size distribution which leads to a lower degree of aeration and a higher degree of water retention (e.g. black peats); and

(3) intermediate materials with pseudo-elastic behaviour that shrink in response to drying, but recover almost all of their initial properties on re-wetting (e.g. white *Sphagnum* peats).

CONCLUSION

Few of the materials available on the market possess entirely suitable aeration and water retention qualities. In fact, only certain white *Sphagnum* peats and some mixtures of different materials are capable of fulfilling this physical role for the plant. There are no completely satisfactory alternatives to peat, in terms of quality and availability, and peat remains indispensable for soil-less horticultural production systems. Nevertheless, some complementary products can be added to peat, especially to improve growing medium aeration, and this contributes indirectly to reducing the use of peat in horticulture.

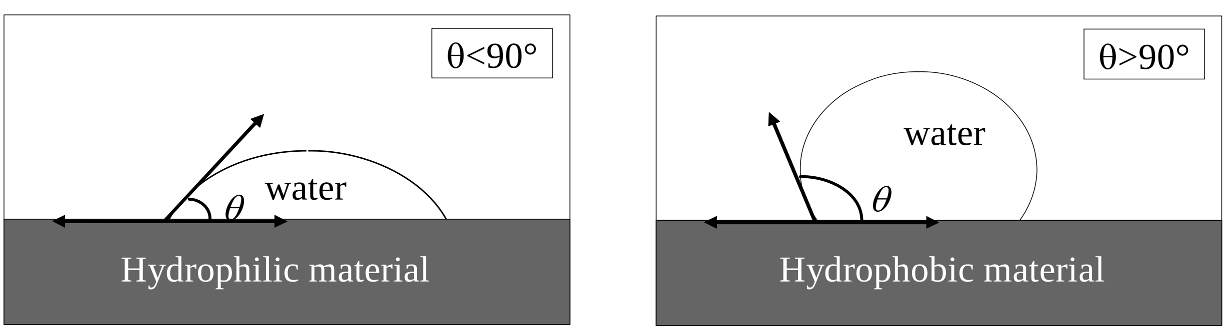


Figure 5. Contact angle (θ) of a drop of water on a solid surface.

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