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Alternative Substrates for Potted Ornamental Plants Based on Argentinean Peat and Argentinean River Waste: A Review

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ABSTRACT

Choosing the right media to grow quality pot plants is a key factor in crop production. Horticultural container media may be formulated from a variety of materials, with the goal to optimize physical and nutritional characteristics. However, suitable organic amendments are becoming expensive and increasingly difficult to obtain. Although Argentinean peat does not seem to be a fully acceptable substitute for *Sphagnum* Canadian peat, it would be an alternative pot plant growing media when combined with river waste. Alternative substrates, which are well characterized and corrected by suitable mixtures, make it possible to produce better quality plants, more rapidly and avoid the over-exploitation of natural *Sphagnum* peatlands. Chemical and physical characteristics of Argentinean peat and river waste-based alternative substrates for different ornamental perennials and bedding pot plants are also discussed.

Keywords: bedding plants, chemical properties, growing media, physical properties, transplants

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INTRODUCTION

The potted plant industry has undergone a dramatic expansion during the last two decades with potted plants now being readily available in retail stores, as well as nurseries. The marketability of potted plants is greatly influenced by the quality of the plant produced. This has increased the need for a regular supply of a uniform growth medium that has the ability to support vigorous plant growth. Owing to the difficulties of getting soil of a consistent quality and to the possibility of adverse physical problems when soils are potted, most growers use soilless potting substrates. Soilless cultivation systems in horticulture to have been adopted in a commercial scale because of their high production potential, and independence from soil conditions and soil-borne disease, too.

As the rooting volume of a potted plant is very restricted, one important requirement of soilless potting substrates is that they possess a considerable water holding capacity. Soilless potting substrates are frequently based on one component which allows a high plant available water capacity (Menzies and Aitken 1996).

Growing media or components for potting soil mixes are very important production factors in horticulture. Those growing media are usually made up of several components and choosing the right media to grow quality pot plants is a key feature in crop production. Therefore industries and trade companies are very active on the growing media market.

Soilless substrates are used in horticulture for growing seedlings, plant propagation, vegetable production and the production of ornamental plants in pots. The most common substrate for such cultures is prepared with *Sphagnum* peat, due to its high physical and chemical stability and low degradation rate. Although peat is an important growth substrate used in pot plants, it is a limited resource and is protected in some areas of nature conservation grounds. But peat products are not necessarily the optimal growth substrates because of their water-logging tendency and low oxygen availability under watering (Clemmensen 2004).

In areas lacking in indigenous peat deposits and where imported peat is expensive, it is common for potting media to contain high proportions of wood wastes (Chong and Cline 1993; Kuehny and Morales 1998; Gruda and Schnitzler 2004), aged or composted bark and composted sawdust (Manning *et al*. 1995; Menzies and Aitken 1996; Burger *et al*. 1997), or a whole range of waste materials such as rice hulls (Papafotiou *et al*. 2001), ground coconut husks (de Kreij and van Leeuwen 2001; Abad *et al*. 2002); composted municipal or industrial solid wastes (Hicklenton *et al*. 2001;

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Zubillaga and Lavado 2001) and river waste (Di Benedetto *et al*. 2004).

HIGH QUALITY PEAT

Nowadays peat is used in many different situations as a mulch, substrate and soil structure amendment for most cropping systems; peat is also used for the production of commercial energy (Schilstra 2001). The cost of high quality peat for horticultural use, together with the declining availability of peat in the near future due to environmental constraints (Frolking *et al*. 2001), make evident the need to look for alternative materials (Guerin *et al*. 2001; García-Gomez *et al*. 2002; Di Benedetto *et al*. 2006b).

The properties of light peat are primarily determined by the composition of plant species that make up the peat and secondarily by particle size distribution of the peat. The wettability and water retention of peat media are also strongly dependent on their surface properties as organic materials often become hydrophobic and unwettable when allowed to dry out. Dark peat properties depend both on the floristic composition and the degree of humification, while those of black peat are almost entirely dependent on the degree of humification.

Peat used in soilless container media for commercial plant production is harvested from North Hemisphere wetland ecosystems at rates considered unsustainable by wetland ecologists (Barber 1993; Barkham 1993; Buckland 1993). Although the peat industry argues that peatlands can be managed on sustainable levels, it recognizes that alternatives to peat must be developed to meet consumers' environmental concerns and to contend with an increased regulation of peatland exploitation (Robertson 1993). *Sphagnum* sp. and sedge are the most common types of peat used in horticulture, with sedge peat regarded as the inferior material due to its lack of uniformity and tendency to lose volume when wet. In the last two decades, the superior (and more expensive) *Sphagnum* peat has shown wide swings in price and availability (Meerow 1994; Perez-Murcia *et al*. 2005). These problems are accentuated because Australian peat is unsuitable for its incorporation in potting substrates due to its high heavy metals concentration.

ARGENTINEAN PEAT

The presence of wetland ecosystems in Southern Argentina (15,300,000 tons of *Carex* and *Sphagnum* peat) offers a potential substitute for Canadian peat. Wetland for *Carex* sp. peat extends from 46°S to 42°S while *Sphagnum magellanicum* peat is limited to Tierra del Fuego province (55°S to 52°S) (Di Benedetto and Klasman 2005; **Fig. 1**).

There are some 500 km^2 of peat bogs on the Isla Grande de Tierra del Fuego (Argentina). These deposits constitute some 95% of Argentina's peatlands; other peat bogs exist in the highland valleys of the Andean Cordillera and other areas. However, economic exploitation of peat is almost entirely confined to Tierra del Fuego, where relatively small amounts (3,000 m^3 per annum) are extracted almost entirely for use as a soil-improvement agent. Consumption of peat for fuel is currently negligible.

The Survey of Energy Resources published by the World Energy Council of the International peat Society in 2001 showed a proved peat recoverable reserve of 80 million tons, within a total proved amount in place of some 90 million tons. A further 50 million tons of (unproved) resources are estimated to be present, of which some 15 million tons are deemed to be recoverable.

Although, there is only limited research so far to support the use of Argentinean *Sphagnum magellanicum* and *Carex* sp. peat as a growth media component, previous results have showed a low physical stability, a low rewettability and a decrease in plant growth when it was used for bedding pot plants such as *Begonia semperflorens-cultorum*, *Gerbera jamensonii*, *Impatiens wallerana* and *Viola wittrockiana* (Di Benedetto *et al*. 2000, 2002).

ARGENTINEAN RIVER WASTE

The Argentinean north-east lands which extends from 34°S to 27°15'S (166.980 km^2) show a subtropical climate with

Fig. 1 Isla Grande de Tierra del Fuego geographic localization.

Fig. 2 River waste ('tropical peat') deposits removed from lakes and rivers. Concordia (Entre Ríos, Argentina).

rainfalls over 1,000 mm with an important proportion of it (10%) related to rivers, lakes and estuaries where it is possible to find anaerobic composted plant sediments named as 'river waste' or 'tropical peat' which has been indicated as a substitute of *Sphagnum* peat for soilless perennial pot plant growing media (Di Benedetto *et al*. 2004).

River waste is the result of the accumulation of plant residues under an anaerobic environment, which is dredged from river or lake banks. The sedimentary organic matter is derived from the delta plain vegetation and is highly dominated by phytoplasts (plant debris). This large input of leaves and petioles into subaquatic sediments originated from soft-plant tissues are preserved chemically and structurally under an environment where the organic matter is in an excessive concentration compared with the oxidants utilized by microorganisms. The result is a fine-grained, black, oozy sediment deposited in the bottom of the coasts (**Fig. 2**). For some time, it was used as a locally available material to prepare soilless growing media for containerised crop production. Only during the past few years has this material become commercially popular, and now it sounds as a successful Canadian peat substitute for perennials (*Achillea millefolium*, *Alchemilla mollis*, *Anacyclus depressus*, *Coreopsis grandiflorum*, *Cyclamen persicum*, *Chrysanthemum coccineum*, *Doronicum orientale*, *Erigeron speciosus*, *Iberis sempervirens*, *Oenothera missouriensis*, *Physostegia virginiana*, *Polygonum capitatum*, *Salvia superva*, *Saxifraga arendsii*, *Sidalcea malviflora*, *Solidago canadensis*, *Veronica repens*, *V. spicata* and *V. teucrium)* and annual bedding pot plants (*I. wallerana* 'Accent', *Petunia × hybrida* 'Ultra' and *V. wittrockiana* 'Saint Tropez') seed-propagated (Di Benedetto *et al*. 2004, 2006b) and as a low quality peat media amendment (Di Benedetto and Klasman 2007b).

It has been indicated that the chemical properties of growing media play a major role because they govern the efficiency of nutrient supply and influence the environmental balance both during and after cultivation (Guerin *et al*. 2001). Electrical conductivity and pH in the growing media are closely correlated with water salinity and alkalinity (Salvador and Balas 2006). Canadian and Argentinean peat, generally have a pH of 4.0 or slightly below. Thus the inclusion of other organic and inorganic materials into the growing substrate should increase the pH to a more acceptable level (Constrisciano and Holcomb 1995; Kuehny and Morales 1998). On the other hand, river waste shows higher pH values and does not require additional corrections. Electrical conductivity was lower for Canadian and Argentinean peat than for river waste (Di Benedetto *et al*. 2006b). River waste showed a lower total organic matter content and a higher cationic exchange capacity. There were only minor differences in nutrient contents between river waste, Canadian peat and Argentinean (both *Sphagnum magellanicum* and *Carex* sp.) peat (**Table 1**).

PEAT AND RIVER WASTE PHYSICAL PROPERTIES

One of the most important considerations in formulating a container medium, regardless of the materials used, is the particle size of the individual components. Particle size largely determines the physical properties (total porosity, air-filled porosity, bulk density and container porosity) of the medium (Noguera *et al*. 2003).

Aeration in soilless mixes is often reported to be a problem (Caron and Nkongolo 1999). After the partial saturation and the complete drainage of potted media, a very small perched water table occurs at the bottom of the pot, resulting in media equilibrated at very high water potentials and many of the substrate pores tend to remain saturated under these conditions, further increasing the risk of root asphyxia if the period of saturation of a large proportion of these pores is prolonged. The air-filled porosity of high quality peat-based soilless mixes may be very low at these high water potentials, despite a very high total porosity. Air-filled porosity is therefore used as a standard index to guide substrate manufacturing, and is generally measured on disturbed media packed into cylinders and equilibrated at an arbitrary potential. Simulation studies have shown the importance of characterizing air-filled porosity at more than one water potential since air-filled porosity is dependent on container geometry for a given substrate. Traditionally, the aeration status of a substrate is assessed from air-filled porosity or air volume measurements. Air-filled porosity is determined after saturating and draining the pots or cylinders to potentials of -10 or -6 cm. depending on the method used. The volume of air replacing the volume of water being drained between saturation and 'container capacity' represents the air-filled porosity or air capacity of the substrate at these potentials, which correspond to the average potential existing after saturation and drainage in 20- or 12-cm high pots. The water potential of -10 cm was initially chosen because it corresponded to the water potential existing in benches used for ornamental plant production. Spomer (1975) reported the effects of pot height on air-filled porosity. Bilderback and Fonteno (1987), Fonteno (1989) and Ruter and van de Werken (1991) showed that container geometry, as well as container height, can have a pronounced effect on air-filled porosity.

With the increased use of pots of variable size, many

Table 1 Chemical properties and nutrient contents for river waste, Canadian and Argentinean peat.

	Canadian peat	Argentinean peat		River waste
		Sphagnum magellanicum	***Carex* sp.**	
Organic matter (%)	81.07	82.32	80.44	69.92
pH	4.85	4.81	4.51	5.15
Electrical Conductivity (dS m^{-1})	0.17	0.11	0.56	2.02
N-total (%)	1.71	0.90	1.13	1.14
P (μg ml^{-1})	4.57	5.26	9.50	9.74
K (meq/100g)	1.02	0.78	0.44	1.05
Ca (meq/100g)	22.11	12.18	15.22	26.40
Mg (meq/100g)	4.19	1.98	1.50	2.32
Na (meq/100g)	1.03	0.21	0.86	2.24
Cationic Exchange Capacity (meq/100g)	36.70	24.05	26.50	41.00

authors have pointed out the need to adjust air-filled porosity estimations according to pot size and geometry (Caron and Nkongolo 1999); these findings stressed the need to characterise the entire desorption curve to obtain a more accurate index of the air-filled porosity existing in pots, and Fonteno (1989) demonstrated how such information can be used to calculate the aeration in pots of variable size and geometry.

Several developments also suggest that the air exchange properties within the substrate are considered to obtain more reliable indexes of aeration. In Fonteno's approach (1989), the information on the water desorption curves is obtained from independent measurements made on cores, measurements which are then extrapolated to predict the overall aeration status in pots. However, these measurements are taken on disturbed substrate samples and substrate disturbance can have a pronounced effect on the water desorption characteristics used in the calculation procedure (Paquet *et al*. 1993). A more accurate characterization can be obtained using tension tables with soft surfaces that allow the direct measurement of these properties in potted substrates (Topp and Zebchuk 1979). The development of non-invasive techniques for the *in situ* measurement of both soil water potential (tensiometry) and water content in peat substrates (Paquet *et al*. 1993; Anisko *et al*. 1994) also reduces the impact of substrate disturbance on air-filled porosity measurements and makes it possible to determine the air-filled porosity of a substrate while taking into account both the size and geometry of the container.

The air-filled porosity in potted substrates can be determined using time domain reflectometry (Topp *et al*. 1980) by measuring the water content at saturation, θ_s, and again at container capacity, θ_c, after free drainage. Air-filled porosity is thereafter calculated using the following relationship:

$$\theta_a = \theta_s - \theta_c$$

When characterizing aeration processes using gas diffusivity, air-filled porosity is very important since air diffusion within the substrate depends on the functional relationship between three different factors: the gas diffusion in free air, D_a; the air-filled porosity (θ_a), and the tortuosity factor (τ), an index linked to the effectiveness of the pore system to transmit gases. King and Smith (1987) showed that in peat, all three factors can be linked to the measured gas diffusivity, D_s, through the relationship:

$$D_s = D_a\, \theta_a/\tau$$

Because aeration properties cannot be easily changed during plant growth and air-filled porosity tends to decrease with time (Nash and Laiche 1981; Di Benedetto *et al*. 2003), high initial aeration levels are essential.

In horticulture, one of the most important criteria for assessing the physical quality of *Sphagnum* peat-based artificial mixes is the percentage of pore space and the proportion and amount of water and air stored within that pore space. In mineral soils as well as in artificial media there is no universally accepted critical value for air-filled porosity although it was stated that at least 10% of the pore space should be filled with air after irrigation and drainage to support plant growth. On the other hand, Verdonck *et al*. (1983) reported that a substrate should contain at least a 20% volume of air and a 20-30% volume of easily available water at a water potential of -1.0 kPa for optimal growth conditions.

In artificial mixes, the air content in a substrate is of concern because air-filled porosity cannot be changed easily after manufacturing and, aeration problems are often encountered by growers. Consequently, peat-based substrates are routinely amended with various materials such as large-particle-size: perlite, rockwool, expanding clays, sands, wood bark, compost, polystyrene and polyurethane to obtain a high air-filled porosity. For example, Bunt (1974) found that fine (<0.5 mm) mineral particles mixed with peat reduced media air-filled porosity but had no effect on readily available water. Larger particles (>0.5 mm) reduced readily available water by more than 25% without affecting air-filled porosity (Caron and Nkongolo 1999).

Structure is mainly related to the bulk density of the media, which is a measure of the degree of compaction. Compaction decreases total porosity and hence diminishes aeration, but increases the mechanical strength of the medium.

Table 2 showed only minor total porosity and container capacity differences between river waste, Canadian and Argentinean peat, but significant differences for air-filled porosity for Argentinean (*Sphagnum magellanicum* and *Carex* sp.) peat; river waste had a significant highest bulk density.

PEAT AND RIVER WASTE: STABILITY OF PHYSICAL PROPERTIES

Soil aeration is determined by the air-filled pore space and is, therefore, strongly influenced by soil drainage and soil compaction. Soil compaction decreases the oxygen diffusion rate and increases the root-soil contact. Both aspects have a negative effect on the potential specific supply rate of oxygen. During compaction, the largest air-filled pores disappear and are replaced by smaller, mainly water-filled pores. The decrease in air-filled porosity is 1.5-2 times larger than the decrease in total pore space. The resulting decrease in the oxygen diffusion coefficient depends on the geometry and stability of the network of air-filled pores and the degree of deformation during compaction. Consequently, this decrease is more pronounced in materials with a low than with a high stability (Boone and Veen 1994).

For container-grown plants, stability of the physical properties of substrates is a primary concern because any change in these properties may negatively affect plant growth. Substrate quality and stability are related to physical attributes such as particle-size, pore-size distribution and arrangement, which influence water and gas storage, and exchange properties.

It is generally believed that properties of substrates initially considered appropriate for plant growth may deteriorate upon aging due to several processes. The air storage decreases as substrates age because of settling and segregation of particles of variable sizes (Bures *et al*. 1993a), shrinkage upon drying (Bures *et al*. 1993b), organic matter decomposition, and physical breakdown of fibbers (Nash and Laiche 1981). These processes generally result in decreased pore sizes. As pore size decreases, air-filled porosity has often been observed to decrease associated with an increase in water retention.

However, it has been shown that the hydraulic conductivity of a substrate may increase with time; such an effect may also occur for gas diffusivity, since these two properties are functionally linked through pore size distribution and tortuosity (Allaire *et al*. 1996). Increased gas diffusivity

Table 2 Physical properties for River Waste, Canadian and Argentinean peat.

	Canadian peat	Argentinean peat		River waste
		Sphagnum magellanicum	*Carex* sp.	
Total porosity (%)	85.72	85.50	78.56	86.80
Air-filled porosity (%)	20.94	15.94	17.00	22.80
Container capacity (%)	22.78	25.94	23.00	24.00
Bulk density (g cm^{-3})	0.14	0.18	0.23	0.60

Table 3 Changes in total porosity (%) and air-filled porosity (%) of growing media formulated with two *Sphagnum* peat sources (Canadian and Argentinean) at the transplant stage and at the end of the growing pot period.

	Canadian peat	Argentinean peat
Initial total porosity (%)	88.1 Aa	83.2 Aa
End total porosity (%) (transplant)	80.2 Aa	45.7 Bb
End total porosity (%) (pot)	68.5 Ab	30.4 Bc
Initial air-filled porosity (%)	21.2 Aa	20.0 Aa
End air-filled porosity (%) (transplant)	20.5 Aa	15.8 Bb
End air-filled porosity (%) (pot)	18.0 Aa	14.4 Bb

Different capital letters indicate statistical differences ($p \leq 0.05$) using Tukey's test between peat sources while different lower case letters indicate statistical differences ($p \leq 0.05$) over time.

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has also been linked to decreased particle sizes at constant air-filled porosity (Nkongolo and Caron 1999), through an increase in pore effectiveness. Therefore, physical alteration of fibres in substrates may lead to an increase of aeration or to a lack of change in aeration properties despite a decrease in air-filled porosity. This possibility has received no attention so far. Allaire-Leung *et al.* (1999) and Di Benedetto *et al.* (2003) indicated that physical alterations of the substrates may not lead to the deterioration of their quality during pot plant growth, such as *B. semperflorens-cultorum*, *G. jamensonii*, *I. wallerana* and *V. wittrockiana*, as first through, but rather maintain or improve with time due to root growth.

Container media are essentially mixtures of different-sized particles. Physical properties of container media depend on the packing characteristics of particles, which are affected directly by their size distribution. Thus, to obtain container substrates with optimal properties, components are mixed in various proportions. When materials of different particle sizes are mixed, fine particles fill the pores between the large particles, resulting in reduction of the final volume of the mixture in relation to the original volume of the separate materials (shrinkage). Thus, the total porosity of the medium is decreased. Degree of shrinkage depends on the relative size of mixed particles and on particle size distribution (Bures 1993a).

The breakdown for peat during incubation is strongly correlated to the degree of decomposition of peat when extracted from the bog. Peat that has a higher level of decomposition is more stable. It has been shown (Prasad and O'Shea 1999) that peat tested from Northern Europe are likely to break down rapidly, compared to the more decomposed tested peat from Canada, even when these peat have been fractioned. The use of peat of low degree of decomposition such as Argentinean peat (unpublished data) and wood fibres for long term crops could cause problems due to breakdown and the consequent reduction for air space.

The bulk density of peat increases according to the rising in degree of humification. The bulk density of *Sphagnum* peat growth medium (H1-3) is about 0.04-0.08 g cm^{-3} at a corresponding total porosity of 97-94%. During its use as a growth medium, peat settles and decomposes, and so tends to become more compact. The presence of coarse particles, such as fibres and wood residues 9-18 mm in diameter, increase the air filled porosity of the medium (Byrne and Carty 1989). Wood residues in such a mixture may, however, decompose relatively quickly and increase media compactness (Gruda and Schnitzler 2004); a different pattern could be shown when river waste was used (Di Benedetto and Klasman 2007b).

The results for total porosity (%) and air-filled porosity (%) plotted in **Table 3** (from Di Benedetto *et al.* 2006a) showed that at the beginning of the experiment, there was no difference in total porosity (%) between growing medias based on Canadian or Argentinean peat for *I. wallerana* 'Accent', *P.* × *hybrida* 'Ultra' and *V. wittrockiana* 'Saint Tropez'. At the transplant stage (forty days from sowing for bedding pot plants), a decrease in this physical parameter for the mean of the samples was found mainly when growing medium was formulated with Argentinean peat. At this growth stage, total porosity for a medium formulated with Canadian peat was significantly higher than for an Argentinean peat-based medium. Some weeks later, at the sales stage for most of the bedding plants tested, an increase in differences in total porosity between peat sources was found. A similar pattern occurred in the air-filled porosity: there were no statistical significant differences between Argentinean and Canadian peat-based media at the beginning of the experiment, but both, at the transplant stage and at the end of the experiment showed slight but significant differences in the air-filled porosity in favor of Canadian peat. This differences in substrate physical properties significantly decreased plant quality (leaf area, plant height and flower number), plant growth and plant productivity (estimated through to the production cycle).

If the physical quality analysis of media were limited to the initial porosity, it would be possible to suggest the Argentinean peat as a high quality medium similar to Canadian *Sphagnum*. However, when the values for total porosity were included eight weeks later, Argentinean peat showed a significantly lower porosity than Canadian peat. These results have shown clearly that the peat tested from Argentinean wetlands is likely to break down rapidly, compared to the more decomposed peat from Canadian wetlands.

On the other hand, river waste has been indicated as a potential amendment for low quality Argentinean peat. Data in **Table 4** shows that there were significant total porosity changes related to the percentages of river waste and Argentinean peat in the mix and total porosity decreased from beginning to the end of the experiments. The use of river waste increased total porosity and enhanced the stability of Argentinean peat when it is included up to the 60% of the mix (Di Benedetto and Klasman 2007b).

Large quantities of rice hull is produce annually that has to be disposed in a friendly way to the environment although there is limited information (Papafotiou *et al.* 2001a, 2001b) on the availability of it as a growing medium component for ornamentals and critical experiments are lacking. Mail rice hull chemical properties included: pH= 5.15; EC (dS m^{-1}) = 2.02; OM (%) = 69.92; N_{total} (%) = 1.14; P (µg ml^{-1}) = 9.74; K (meq/100 g) = 1.05; Ca (meq/100 g) = 26.40; Mg (meq/100 g) = 2.32; Na (meq/100 g) = 2.24 and CEC = 41.00. The use of rice hull, indicated as a substitute for perlite and vermiculite, increased aeration and drainage

Table 4 Porosity changes from growing media tested between the beginning and the end of the experiments.

River Waste (%)	Initial Porosity (%)	End Porosity (%)
0	55.23 Ac	36.25 Bc
10	57.34 Ac	37.88 Bc
20	49.38 Ac	35.19 Bc
30	50.01 Ac	39.76 Bc
40	53.67 Ac	42.00 Bc
50	59.86 Ac	54.26 Bb
60	65.61 Ab	57.76 Bb
70	73.35 Ab	59.75 Bb
80	90.65 Aa	61.01 Bb
90	92.72 Aa	65.05 Ba
100	95.64 Aa	72.00 Ba

Substrates were prepared by an inverse proportion of river waste and Argentinean *Sphagnum* peat. Different capital letters indicate statistical differences ($p \leq 0.05$) using Tukey's test between initial and end sample harvest while different lower case letters indicate statistical differences ($p \leq 0.05$) between river waste percentages in the media.

Reprinted from **Di Benedetto A, Klasman R** (2007b) River waste as a potentially amendment for low quality *Sphagnum* peat. *European Journal of Horticultural Science* **72** (in press), ©2007, with kind permission from Verlag Eugen Ulmer KG, Stuttgart.

properties in *Sphagnum* and river waste based-media and worked for *V. wittrockiana* 'Saint Tropez', *P.* × *hybrida* 'Ultra' and *I. wallerana* 'Accent' bedding pot plants (Di Benedetto *et al*. 2006b).

WATER AND GROWING MEDIA QUALITY RELATIONSHIPS

In plant production, achievement and maintenance of favourable water and aeration conditions in growth media are crucial for crop growth and quality. However, only limited information is available concerning the effect of irrigation regime, which can vary in irrigation frequency and targets the water content on the actual water and aeration conditions in containerized peat growth media.

The great water retention in high quality peat at desorption affects the suitability of the irrigation method. If *Sphagnum* peat is irrigated frequently with relatively small quantities of water (Heinskanen 1993), all the water may be retained in only the upper part of the medium, while the lower parts of the container remain dry. The amount of water actually received by the medium also may be reduced greatly due to interception by foliage. The intercepted water is lost by evaporation, especially when plants are irrigated with a very fine mist of water and the evaporative rate is high. Transpiration of growing plants may decrease the water content in the lower parts of the container. In addition, the most peat surface may promote growth of algae and mosses, which may block the pores of the peat structure and hence restrict aeration of the medium. Too frequent irrigation may thus be accompanied by inadequate availability of water and O_2 for plants. Therefore, although the average aeration limit would be exceeded temporarily, low-humified peat medium, such as Argentinean *Sphagnum maguellanicum* and *Carex* sp. peat, may require relatively infrequent re-irrigations (unpublished data), during each of which a sufficiently large quantity of water should be applied within a short time. However, due to their lower water retention capacity, small containers require more frequent irrigation than large ones (Heinskanen 1995b).

The high water retention of pure peat, which is further increased by shrinkage of the medium at desorption, yielded low air-filled porosity at high matric potentials. The addition of coarse perlite to peat decreased the shrinkage markedly and also tended to increase the low saturated hydraulic conductivity of peat, which had initially been rather low. In all the media studied, the amount of water that is easily available for plants (water content retained between -1 and -10 kPa matric potential) was relatively high.

The shrinkage of the media did not considerably affect water retention within the matric potential ranges studied. Thus the water availability to plants grown in these media is not likely to be affected markedly by the shrinkage. Nevertheless, the shrinkage of the medium tends to increase bulk density causing an increase in water retention expressed per apparent, shrunk volume of the medium at a specific matric potential compared with those expressed for the initial saturated volume. It was shown that when added to low-humified *Sphagnum* peat in a proportion of less than 50%, the additives studied did not markedly alter the water retention characteristics of peat (Heiskanen 1995a).

The fact is that Argentinean peat is likely to break down rapidly compared to the more decomposed peat from Canadian wetlands (Di Benedetto *et al*. 2006a), the presence of small size particles close the air-filled pores at the top of the plug with a correlative increase in the degree of compaction of the media. The growth of algae populations on the top of the plug would also decrease water distribution and lead to a water downward gradient. This effect is limited by the short time between sowing and transplant (35 days) in nursery plug systems, and it would be increased when pot plant industry includes Argentinean peat as a growing media or when cell number per try are increasing (unpublished data).

Availability of oxygen to plant roots depends on the rate of gaseous exchange between the atmosphere and the growing medium. In order to ensure sufficient supply of oxygen to the roots, aeration should provide adequate diffusive intake of O_2 and removal of excess CO_2 in the growing medium. Air volume or air-filled porosity of the growing medium is commonly used to estimate the level of aeration and the availability of oxygen to plant roots. Increasing water content in the growing medium reduces air-filled porosity and aeration, which in most plant species can eventually lead to water logging and hypoxia (Heinskanen 1995b).

For growing media in horticulture it is commonly recommended that air-filled porosity, which is usually determined at a fixed matric potential of -1 kPa, should be above 10-20%. Furthermore, growing media, container types and plant species may differ in their aeration requirements. The need for air-filled porosity in containers may also differ from that in thick bed cultures. Therefore, as a general guideline based on the previous discussion, actual air-filled porosities above 20% by total wet volume can be considered non-critical for plants but in light peat may still limit growth (Heiskanen 1997).

However, although some information is available about the implications of the properties of the high quality peat-based growing media and containers for aeration and plant growth, relatively little is known about the actual temporal changes in aeration during culturing of container plants. Therefore, in order to determine suitable nursery-management practices (e.g. irrigation, shading, and ventilation) for promoting good growth and quality of plant stock grown in peat-based growing media, further information about the effects of irrigation, evaporation and container on the actual aeration and plant growth is needed.

In contrast, Argentinean river waste showed a high water retention capacity and a higher rewettability than peat for which water logging would be a common situation. The use of rice hull would be indicated as a substitute for perlite and vermiculite, which increased aeration and drainage properties in *Sphagnum* and river waste base-media; however, would increase water frequency when rice hull was used for *I. walleriana* 'Accent', *P.* × *hybrida* 'Ultra' and *V. wittrokiana* 'Saint Tropez' bedding plants (Di Benedetto *et al*. 2006b).

GROWTH AND GROWING MEDIA RELATIONSHIPS

The use of transplant is the most reliable method to ensure adequate crop establishment of commercial plantings of various high-value ornamental and vegetable crops. Transplant production for commercial growers is a highly competitive industry in which the ability to deliver the specified quantity and quality of transplant at a specified time is critical to customer satisfaction. This is also a highly mechanized industry. Therefore, quick, uniform seedling emergence as well as a rapid, consistent plant growth is essential for efficient commercial transplant production.

Vegetable and ornamental transplants are grown at high densities in polystyrene containers with moulded cells in the shape of an inverted pyramid. Growers have started using plugs with even more restricted root volume to improve production efficiency by increasing the number of plants per tray and reducing the need for additional growing space. Mechanization of container filling requires a consistent medium of small particle size. Moisture retention by the medium is critical to maintain a rapid growth rate, but aeration is also essential. Water-holding capacity of soil media on a weight or volume basis increases as the pot size decreases, slowing free drainage. Therefore, a very well drained medium is needed for the production of transplants.

An interaction between container design and media quality influence water-holding capacity and air space (Ruter and van der Werken 1991). Bilderback and Fonteno (1987) have indicated that growers consider the container-growth medium combination as a unit and not as two independent factors. The 'root restriction' effects on seedling growth during nursery could increase after transplants and

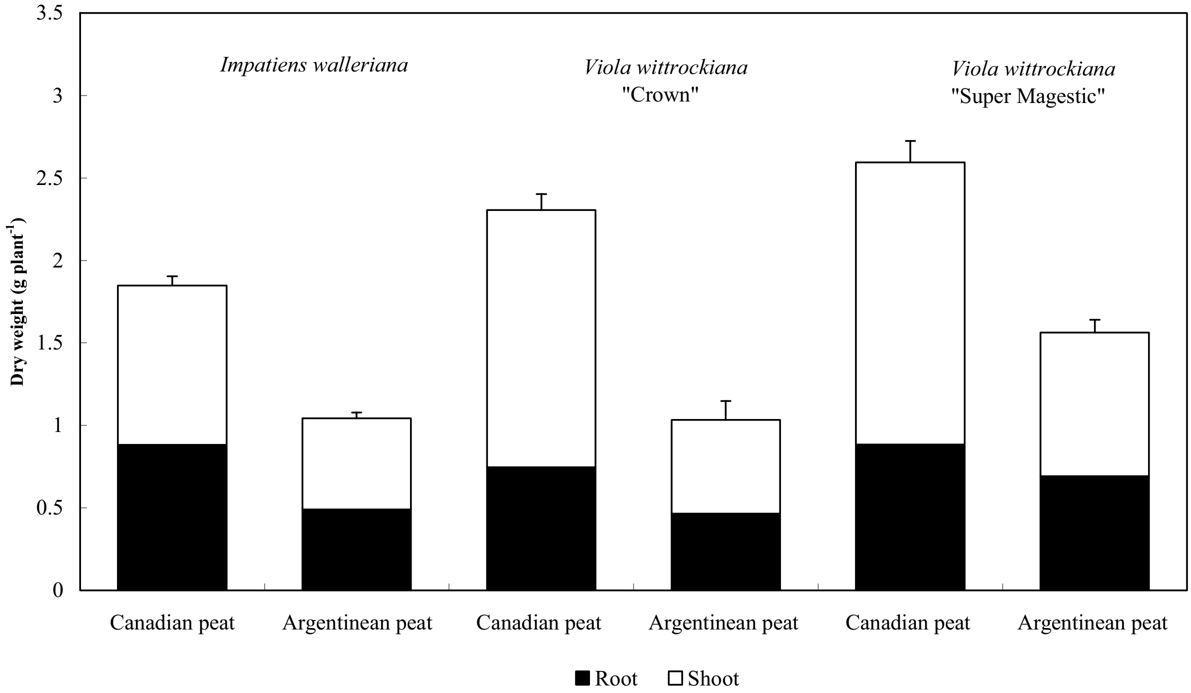

Fig. 3 Dry weight for *Impatiens wallerana* and *Viola wittrockiana* grown with either Argentinean or Canadian peat-based medium at the pot sale stage. Bars are mean of 180 plants for *Impatiens wallerana* "Accent" and forty and sixty plants for *Viola wittrockiana* "Crown" and "Super Majestic" series respectively. Standard errors are indicated in all the cases. Reprinted from **Di Benedetto A, Klasman R, Boschi C** (2006a) Argentinean peat: a poor substitute for Canadian *Sphagnum* peat for ornamental bedding plants. *European Journal of Horticultural Science* **71**, 69-72, ©2006, with kind permission from Verlag Eugen Ulmer KG, Stuttgart.

could limit pot plant productivity (Di Benedetto and Klasman 2004, 2007a).

Substrates for germination are usually high in water content. Lack of air is thus suspected of causing rooting problems, either due to oxygen deficiencies or by accumulation of toxic substances, including bicarbonate and carbon dioxide (Erstad and Gislerod 1994). For plug production, growing media needs to support growth from the time of germination to the time to transplant. Seed germination is a direct result of a grower's ability to provide the proper microenvironment around the seed. Seed germination in the plug tray is very dependent on the moisture applied to the seed. Too much moisture may not allow enough oxygen to reach germination, but insufficient moisture inhibits the physiological processes of germination. Water availability around the seed is related to physical properties of the media too. Due to the short production cycles for transplants, Marchese *et al.* (2006) indicated that Argentinean peat and river waste would be appropriate amendments for Canadian peat. On the other hand, as the seedling quality at the transplant stage was related to potted *Verbena* × *hybrida* Quartz Series plant biomass and photosynthetically active area, the higher total leaf area and dry weight from media from river waste growing base-media allowed to optimize post transplant growth.

For potted grown plants, stability may be achieved over a longer time than for nurseries; the physical properties of growing media are of primary concern because changes in these properties may negatively affect plant growth. Substrate quality and stability are related to physical attributes such as particle-size, pore-size distribution and arrangement, which influence water and gas storage, and exchange properties as was previously discussed. The marketability of potted plants is greatly influenced by the quality of the plant produced.

In view of the need for progressive peat replacement, the first step towards the use of non peat-based substrates is already clear because those substrates would be able to produce plants of better or equal quality than on the control substrate (peat-base media). Alternative substrates must be used increasingly to include horticulture in a sustainable agricultural system (Guerin *et al.* 2001).

Fig. 3 shows that there were significant differences in dry matter production of *I. wallerana* "Accent" and *V. wittrockiana* "Crown" and "Super Majestic" between Canadian and Argentinean peat-based media at the transplant stage; the same results for *Chrysanthemum multicaule*, *Pelargonium* × *hortorum* 'Maverick' and *Salvia splendens* 'Caraviniere' were found (Di Benedetto *et al.* 2006a). These results were due to a higher dry weight for both root and shoot in Canadian peat and indicate the incapacity of Argentinean peat to fully substitute Canadian peat.

Plant growth is related to both photoassimilate gain and partitioning between different organs such as roots and shoots and affect post-sale adaptation for most bedding plants. *P.* × *hybrida* 'Ultra' and *V. wittrockiana* 'Saint Tropez' dry weight gain was highly sensitive to a change of a commercial growing media from alternative substrates while *I. wallerana* 'Accent' gave better results in most of growing media tested (Di Benedetto *et al.* 2006b; **Fig. 4**).

Although Argentinean peat showed deeper restrictions when the crop cycle is increased, it has been indicated that river waste could be an amendment to the Canadian *Sphagnum* peat for potted perennial plants (Di Benedetto *et al.* 2004) and low quality Argentinean *Sphagnum* peat for *Gypsophila muralis* 'Garden Bride' (Di Benedetto and Klasman 2007b; **Fig 5**).

Gipsophyla muralis 'Garden Bride', a pot plant with a high sensitivity to low quality growing media, showed that total dry weight is related to initial porosity as indicated by a high correlation coefficient (R^2 = 0.916); higher values were achieved when high percentages of river waste were included in the growing media but, non significant differences in dry weight were found starting from a mix of river waste:Argentinean *Sphagnum* peat of 60:40 (v/v).

Agriculture is thought to be a major contributor to some present-day environmental problems such as those of water pollution by fertilizers and pesticides. Groundwater pollution by nitrate is a serious problem in the European Union and in many developed countries, and has been reviewed (Ramos *et al.* 2002).

Greenhouse container crop production requires frequent

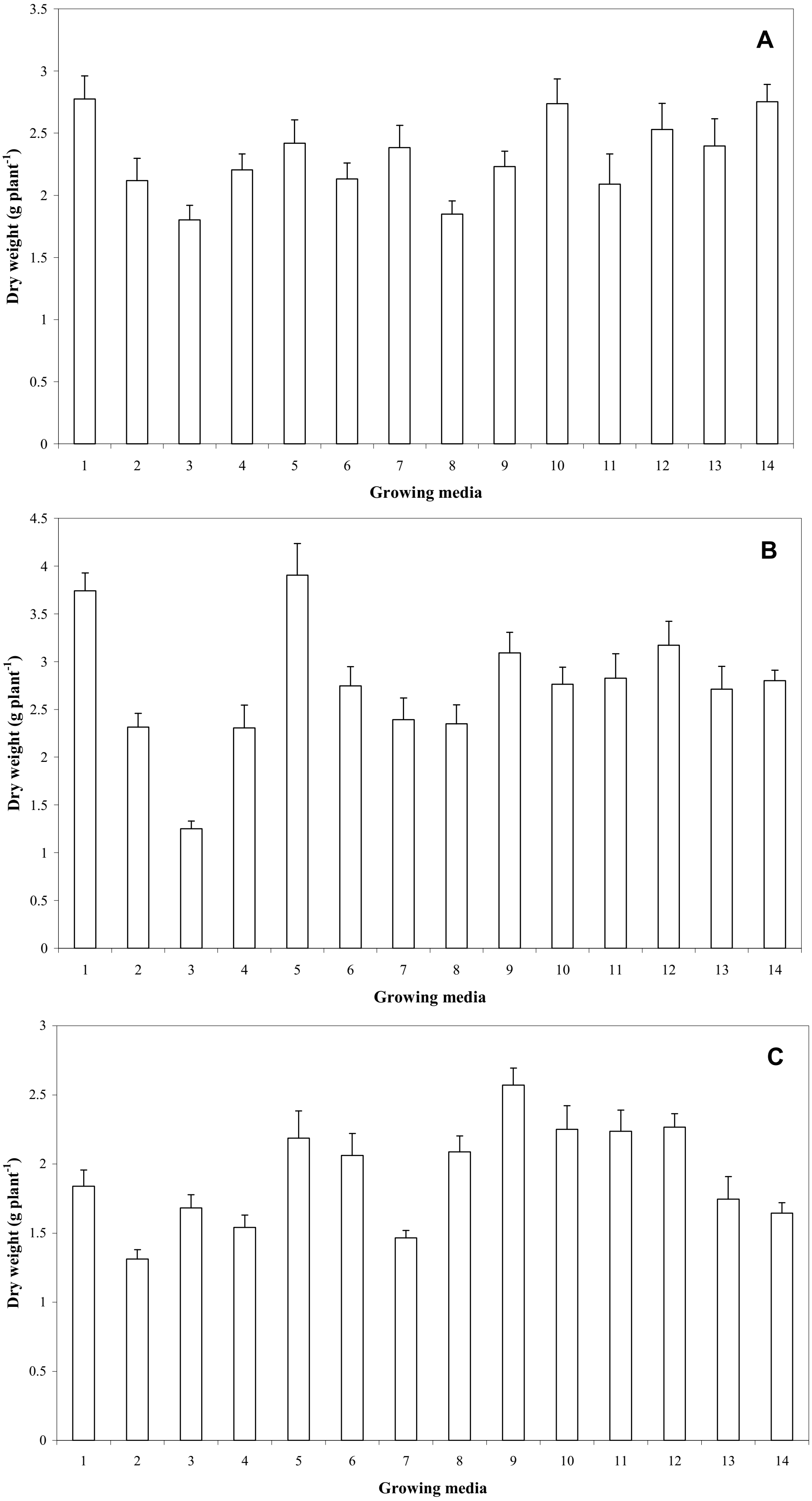

Fig. 4 The effect of different growing media on dry weight gain for three bedding plants: (**A**) *Viola wittrockiana* 'Saint Tropez'; (**B**) *Petunia* × *hybrida* 'Ultra'; (**C**) *Impatiens wallerana* 'Accent'. Bars are mean of twenty replicates and Standard Errors are indicated. Treatments: **1**: Canadian peat (80%) + Vermiculite (10%) + Perlite (10%); **2**: Argentinean *Sphagnum* peat (80%) + Vermiculite (10%) + Perlite (10%); **3**: Argentinean *Carex* peat (80%) + Vermiculite (10%) + Perlite (10%); **4**: Argentinean *Sphagnum* peat (40%) + *Carex* peat (40%) + Vermiculite (10%) + Perlite (10%); **5**: River Waste (80%) + Vermiculite (10%) + Perlite (10%); **6**: Argentinean *Sphagnum* peat (80%) + River Waste (20%); **7**: *Carex* peat (80%) + River Waste (20%); **8**: Argentinean *Sphagnum* peat (40%) + *Carex* peat (40%) + River Waste (20%); **9**: Argentinean *Sphagnum* peat (50%) + River Waste (50%); **10**: *Carex* peat (50%) + River Waste (50%); **11**: *Sphagnum* peat (25%) + *Carex* peat (25%) + River Waste (50%); **12**: Argentinean *Sphagnum* peat (40%) + River Waste (40%) + Rice Hull (20%); **13**: *Carex* peat (40%) + River Waste (40%) + Rice Hull (20%); **14**: Argentinean *Sphagnum* peat (20%) + *Carex* peat (20%) + River Waste (40%) + Rice Hull (20%). Reprinted from **Di Benedetto A, Petracchi JC, Marcella G, Montaron P, Chavez W** (2006b) Evaluation of alternative substrates for bedding plants. *International Journal of Agricultural Research* **1**, 545-554, ©2006, with kind permission from Academic Journals Inc., USA.

irrigation and high fertilization rates, which can result in possible contamination of ground and surface water sources. Growers must be concerned with conservation practices, as well as producing high-quality plants (Morvat *et al*. 1998; Marfa *et al*. 2002). Leaching of fertilizers and pesticides from greenhouse container media into the environment is of great concern to floriculture. However, little research has examined the minimum amount of leaching required to obtain maximum container crop growth (Ku and Hershey 1992).

Excessive fertilization, poor drainage, insufficient irrigation, poor water quality, or a combination all can lead to a build-up of substrate salinity that can reduce plant growth. Leaching container substrates is often used to prevent sub-

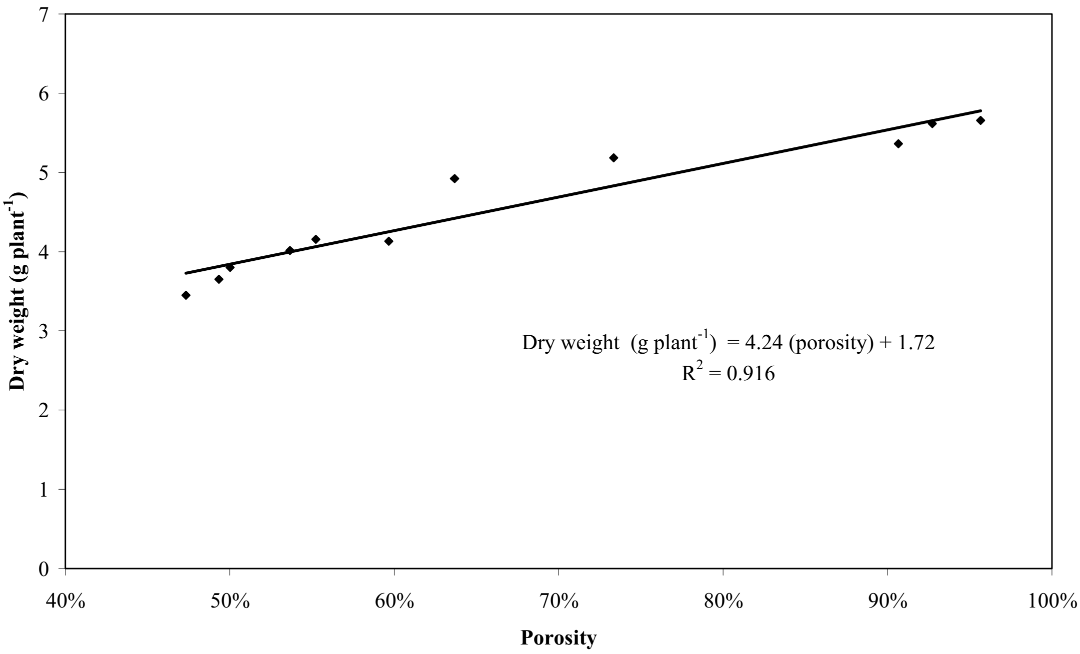

Fig. 5 Total dry weight related to total porosity for substrates performed with an inverse proportion of river waste and Argentinean *Sphagnum* peat. Each point is the mean of forty replicates. Reprinted from **Di Benedetto A, Klasman R** (2007b) River waste as a potentially amendment for low quality *Sphagnum* peat. *European Journal of Horticultural Science* **72** (in press), ©2007, with kind permission from Verlag Eugen Ulmer KG, Stuttgart.

Table 5 Nitrate changes in the leached solution from eight growing media and two fertilization levels at the beginning (Day 10) and the end (Day 50) of the experiment.

Growing media	Nitrate leached ($mg\ L^{-1}$)				Nitrate leached (%)			
	200 $mg\ L^{-1}$ N		400 $mg\ L^{-1}$ N		200 $mg\ L^{-1}$ N		400 $mg\ L^{-1}$ N	
	Day 10	Day 50	Day 10	Day 50	Day 10	Day 50	Day 10	Day 50
Sp	5.0 Aa	2.4 Aa	3.4 Bb	2.9 Aa	1.4 Aa	3.9 Bb	1.3 A	6.1 Ba
SpRW	1.6 Cb	1.5 Ba	2.7 Ba	1.4 Ca	0.6 Ba	3.0 Ba	0.8 B	2.8 Ca
Ca	5.0 Aa	3.0 Aa	4.7 Aa	3.6 Aa	1.5 Aa	5.7 Ab	1.8 A	7.6 Ba
CaRW	1.2 Ca	1.3 Ba	1.1 Ca	1.5 Ca	0.5 Ba	2.9 Ba	0.4 B	3.0 Ca

Different capital letters indicate statistical differences ($p \leq 0.05$) using Tukey's test between growing media while different lower case letters indicate statistical differences ($p \leq 0.05$) between fertilization routines.
Eight substrates were formulated using river waste, Argentinean *Sphagnum* and *Carex* peat, perlite and vermiculite: **Sp** [*Sphagnum* peat (80%) + Perlite (10%) + Vermiculite (10%)]; **SpRW** [*Sphagnum* peat (40%) + River Waste (40%) +Perlite (10%) + Vermiculite (10%)]; **Ca** [*Carex* peat (80%) + Perlite P (10%) + Vermiculite (10%)] and, **CaRW** [*Carex* peat (40%) + River Waste (40%) + Perlite (10%) + Vermiculite (10%)]. A weekly fertilization of 200 and 400 ppm N (1N:0.5P:1K:0.5Ca v/v) from transplant to sale stages were used. Data were the mean of ten percolates from two experiments using *Petunia* × *hybrida* or *Impatiens wallerana*.

strate salt content from increasing up to damaging levels. However, excessive leaching is undesirable because it may contaminate the environment with fertilizers (Ku and Hershey 1997). Some agronomic reasons for precision nutrient management are to minimize pollution from fertilizers or amendments, to avoid heavy metal pollution, reduce salinity, minimize soil erosion and nutrient run-off, and to introduce new species or cultivars having different nutrient requirements to those traditionally specified (Campbell 1994).

Nutrient requirements of container-grown ornamental plants are also influenced by medium composition. Soilless media have a wide range of cation-exchange capacities depending on ratios and types of components in the mix. In most media, adsorbed cations in equilibrium with the medium solution may act as a temporary buffer to reduce nutrient concentrations in the medium solution after leaching or plant nutrient uptake (Knowles 1993).

Bedding plant fertilizer recommendations are usually high (Nelson 1994; Rader 1998). However, unpublished data showed that a high N level fertigation decreased the dry weight of *P.* × *hybrida* 'Ultra' and *I. wallerana* 'Accent' when alternative growing media were tested. The lowest *P.* × *hybrida* 'Ultra' and *I. wallerana* 'Accent' growth was associated with a change in media chemical properties. The lower the nutrient losses from river waste-based growing media the higher nutrient concentration in both growing media and plant tissues which would be able to explain the best plant growth with the lowest fertilization rate.

Nitrogen fertilizer often moves with applied water and leaches out of the pot. This process may potentially contaminate ground and surface waters. Substrates in containers are often leached to prevent substrate salt content and its damaging consequences. However, excessive leaching is undesirable because it may contaminate the environment with fertilizers (Ku and Hershey 1997). The data for *P.* × *hybrida* 'Ultra' and *I. wallerana* 'Accent' under two fertilization routines from **Table 5** (unpublished data) showed that alternative substrates Argentinean peat (*Sphagnum maguellanicum* and *Carex* sp.) and river waste-based lost different amounts of NO_3^-; the substrates with river waste lost the lowest amounts. The nitrogen recovered by plants by multiplying total biomass by N concentration showed that the quantity of nitrogen recovered varied with the species and doses of nitrogen fertilization, being lower for higher nitrate doses. Nitrate losses estimated in this way were larger than those estimated through percolate analysis. Other losses than nitrate leaching or nitrogen retained in substrates might be the main reasons for some of these differences. Here again, substrates with river waste appeared to lose fewer nitrates (**Table 6**). This experiment suggests that leaching of nitrogen from container plants can be minimized and the risk of environmental pollution can be avoided by using alternative river waste-based growing media.

Most flowering pot plants are currently treated with plant growth regulators during development, not only for height control, but also for better branching and flower induction. The triazol growth retardant paclobutrazol is a gibberellin biosynthesis inhibitor that suppresses internodes and long-term growth after sprayed and acts as a medium drench. Media components affect the efficacy of growth retardant drenches.

Dosage and application recommendations are associated

Table 6 Equations for estimating nitrate leaching (Pr>F = 0.005) in substrates formulated with (+) or without (-) river waste (RW) under two fertilization routines.

Regression equations	r
Initial Nitrate leaching (mg L^{-1}) $_{-RW\ 200\ ppm\ N}$ = 0.15 (Porosity) - 8.7	0.87
Initial Nitrate leaching (mg L^{-1}) $_{+RW\ 200\ ppm\ N}$ = 0.05 (Porosity) - 2.4	0.75
Final Nitrate leaching (mg L^{-1}) $_{-RW\ 400\ ppm\ N}$ = 0.15 (Porosity) - 0.3	0.92
Final Nitrate leaching (mg L^{-1}) $_{+RW\ 400\ ppm\ N}$ = 0.09 (Porosity) - 4.5	0.72

Substrates were formulated using Argentinean *Sphagnum* peat with and without river waste. A weekly fertilization of 200 and 400 ppm N (1N:0.5P:1K:0.5Ca v/v) from transplant to sale stages were used. Data were the mean of ten percolates from two experiments using *Petunia × hybrida or Impatiens wallerana* and total porosity were determined. Equations to predict nitrate leaching were developed via linear regression. The significance of the regressions was determined through the Test for zero slopes and Test for zero intercept from Kleinbaum and Kupper (1978).

to the effect of volume related to how much chemical penetrates the canopy of the plants and lands on the soil surface (Latimer *et al.* 1995). Paclobutrazol landing on the medium surface may have been bound to medium particles near the surface and, therefore, no leached into the root zone during watering. It has been shown that the effect of a standard paclobutrazol dose on *P.* × *hybrida* 'Ultra' (Di Benedetto and Molinari 2007) and *V. wittrockiana* 'Banner' (Di Benedetto in press) plant height are related to total porosity determined by the quantity of river waste amendment to peat-base media.

Reduced activity of non-ionic organic chemicals added to soil is often attributed to adsorption reactions with the soil humus; the half-life of the compounds in soil varies considerably between sites, but is generally between 3 and 12 months. The lignin content of *Sphagnum* peat is between 20 to 30%. The oxidation of lignin during microbial decomposition increases its activity and the modified lignin-like compounds are largely responsible for the adsorption of chemical. It has been indicated that mobility in soils and peat is slow and the compound does not pose a leaching hazard (Grimstad 1993). However, Di Benedetto and Molinari (2007) and Di Benedetto (in press) have suggested a higher paclobutrazol leaching for a river waste-based soilless; as many label recommendations for drench concentrations are determined on high quality peat-based media, these results hopefully will aid growers to modifying concentration rates of paclobutrazol for commercial production will be difficult due to the wide range of components used in mixes and differences among sources of these components.

ALTERNATIVE SUBSTRATES

Problems in recent years with peat quality have stimulated interest in alternative substrates. Developing peat alternative substrates is necessary for three different reasons: (1) the resources of peat are limited; (2) the pressure for using waste coming from human or industrial activities increases rapidly and (3) the economic necessity of use locally produced waste products. The biostability of these materials varies and has consequences on the chemical properties of substrates, their management and the growth of ornamental plants. These new materials must have stable physical and chemical properties during cultivation. Because of this, it is necessary to obtain an adequate balance between biostability and culture period.

The increasing demand of growth media for greenhouse horticultural uses, the rising news uses of substrates, and the scarcity and cost of traditional sources, such as *Sphagnum* peat moss, have focused research on new substrate materials (Perez-Murcia *et al.* 2005) or new peat sources. The use of alternative substrates requires knowledge of new characteristics for mixing and also for offering best conditions to plant growth during the culture. The use of peat-substitute based substrate gives, at the moment, worse or erratic results, although Di Benedetto *et al.* (2006b) have suggested that the responses would be different for different bedding pot plant species. In view of the need for progressive peat replacement, the first step towards the use of peat-based substrates is already clear because those substrates are able to produce plants of better or equal quality than on the control substrate (**Fig. 4**). The strong relationship between growth and hydric properties suggest that it is necessary to reconsider the water supply schedule with these substrates (Di Benedetto *et al.* 2000).

Verhagen (1997) has indicated that new growing media are often introduced in horticulture without knowledge about the specific characteristics of the material and demands in horticulture use. Besides this, most new growing media cannot be analyzed exclusively through the conventional methods of analysis used for peat-based media. Differing physical appearance and application in horticulture is demanding a new analytical approach. Results from Di Benedetto *et al.* (2006b) and from **Table 6** are in agreement with his suggestions.

When physical and chemical properties of river waste and Argentinean peat (a material from younger wetlands) were related with light Canadian *Sphagnum* peat (**Tables 1, 2**), most growing media based on Argentinean peat or river waste must be discarded according to 'Ideal substrate' from Abad *et al.* (2001), this is: pH =5.2-6.3; EC (dS m^{-1}) = 0.75-3.49; OM (%) >80; NO_3^- -N (μg ml^{-1}) = 100-199; K^+ (μg ml^{-1}) = 150-249; Na^+ (μg ml^{-1}) = <115; Cl^- (μg ml^{-1}) = <180; SO_4^{2-} -S (μg ml^{-1}) = <960. The alternatives growing media tested in our experiments (Di Benedetto *et al.* 2006b) did not fit the 'ideal substrate' profile. For instance, the alternative media we tested have high pH values, low organic matter and potassium contents. For the rest of the nutrients (calcium, magnesium and sodium), there were low concentrations and little changes between the initial and final concentration, after the two fertilization routines tested.

The low correlation between plant dry weight and total porosity, air filled porosity and other substrate parameters confirm that conventional methods to evaluate peat-based substrates are not suitable for those new substrates: a new analytical approach is needed as was previously indicated (Verhagen 1997; Di Benedetto *et al.* 2006b). This would not be performed only on the initial/final physical and chemical growing media attributes but also on the growth rate and its pollution effects (**Tables 5, 6**).

The physical properties of growth media used in horticulture have been extensively examined. Studies assessing the growth requirements of plants in relation to the physical properties and growth conditions of growth media have been made, although recommendations do not usually cover different plant species during all phases of growth. In addition, the physical characteristics used (porosity, water and air retention) may not be ideal for accurately describing the actual levels of water availability and aeration under different management regimes, growth media and plant growth phases. The pollution consequences (e.g. nitrate leaching characteristics) and plant growth must be considered when evaluating a new media too.

CONCLUDING REMARKS

Finally, I can state that there was different Canadian *Sphagnum* peat amendment potentially available as well as Argentinean peat (*Sphagnum magellanicum* and *Carex* sp.) and river waste for plug and plug/pot production, respectively. But the use of its alternatives with and without rice hull (a potentially perlite-vermiculite substitute) require to reformulate management technology which includes irrigation, fertilization and growth retardant chemicals which are calibrated mainly for high quality *Sphagnum* peat, and physiological support on the growth processes as was previously indicated. Alternative substrates in suitable mixtures make it possible to produce high quality plants. This is an unexpected result on the basis of established methods to evaluate substrate quality based on physical and chemical characteristics for Argentinean peat and river waste. This emphasizes the need for new knowledge about alternative substrates in order to offer the best conditions for plant growth. High concentrate fertigation solution decreases substrate quality parameters and plant growth. Nitrate leaching from the substrates containing river waste was lower, indicating a potential contribution of this new substitute for sustainable pot production systems. The precise combination of alternative substrates in the final media mix and physiological response mechanism for different plants are lacking. Calibration of crop technology for pot plants grown in a specific media mix different to Canadian *Sphagnum* peat is still far but is the subject for intense future research.

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REFERENCES

Abad M, Noguera P, Bures S (2001) National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. *Bioresource Technology* **77**, 197-200

Abad M, Noguera P, Puchades R, Maquieria A, Noguera V (2002) Physico-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants. *Bioresource Technology* **82**, 241-245

Allaire SE, Caron J, Duchesne I, Parent LE, Rioux JA (1996) Air-filled porosity, gas relative diffusivity, and tortuosity: Indices of *Prunus × cistena* sp. growth in peat substrates. *Journal of the American Society for Horticultural Science* **121**, 236-242

Allaire-Leung SE, Caron J, Parent LE (1999) Changes in physical properties of peat substrates during plant growth. *Canadian Journal of Plant Science* **79**, 137-139

Anisko T, NeSmith DE, Lindstrom O (1994) Time domain reflectometry for measuring water content of organic growing media in containers. *HortScience* **29**, 1511-1513

Barber KE (1993) Peatlands as scientific archives of past biodiversity. *Biodiversity Conservation* **2**, 474-489

Barkham JP (1993) For peat's sake: Conservation or exploitation? *Biodiversity Conservation* **2**, 556-566

Bilderback TE, Fonteno WC (1987) Effects of container geometry and media physical properties on air and water volumes in containers. *Journal of Environmental Horticulture* **5**, 180-182

Boone FR, Veen BW (1994) Mechanisms of crop responses to soil compaction. In Soane BD, van Ouwerkerk C (Eds) *Soil Compaction in Crop Production*, Elsevier Science BV, Amsterdam, Netherlands, pp 237-264

Buckland P (1993) Peatland archaecology: A conservation resource on the edge of extinction. *Biodiversity Conservation* **2**, 513-527

Bunt AC (1974) Some physical and chemical characteristics of loamless pot-plant substrates and their relation to plant growth. *Acta Horticulturae* **37**, 1954-1965

Bures S, Pokorny FA, Landau DP, Ferrenberg AM (1993a) Computer simulation of volume shrinkage after mixing container media components. *Journal of the American Society for Horticultural Science* **118**, 757-761

Bures S, Pokorny FA, Ware GO (1993b) Estimating shrinkage of container media with linear and/or regression models. *Communications in Soil Science and Plant Analysis* **24**, 315-323

Burger DW, Hartz TK, Forister GW (1997) Composted green waste as a container medium amendment for the production of ornamental plants. *HortScience* **32**, 57-60

Byrne PJ, Carty B (1989) Developments in the measurement of air filled porosity of peat substrates. *Acta Horticulturae* **238**, 37-44

Campbell LC (1994) Beneficial impact of precision nutrient management on the environment and future needs. *Communications in Soil Science and Plant Analysis* **25**, 889-908

Caron J, Nkongolo VKN (1999) Aeration in growing media: Recent developments. *Acta Horticulturae* **481**, 545-551

Chong C, Cline RA (1993) Response of four ornamental shrubs to container substrate amended with two sources of raw paper mill sludge. *HortScience* **28**, 807-809

Clemmensen AW (2004) Physical characteristics of *Miscanthus* composts compared to peat and wood fiber growth substrates. *Compost Science and Utilization* **12**, 219-224

Constrisciano TM, Holcomb EJ (1995) Growth of bedding plants and poinsettias in mineral wool and mineral wool/peat substrates. *Communications in Soil Science and Plant Analysis* **26**, 485-501

de Kreij C, van Leeuwen JL (2001) Growth of pot plants in treated coir dust as compared to peat. *Communications in Soil Science and Plant Analysis* **32**, 2255-2265

Di Benedetto A (in press) Paclobutrazol decreases dry weight gain in pansy. *Cientifica*

Di Benedetto A, Klasman R (2004) The effect of plug cell volume on the post-transplant growth for *Impatiens walleriana* pot plant. *European Journal of Horticultural Science* **69**, 82-86

Di Benedetto A, Klasman R (2005) Argentinean agroecological availability for ornamental plant growth. *Deutscher Gartenbau* **45**, 38-41 (in German)

Di Benedetto A, Klasman R (2007a) The effect of plug cell volume, paclobutrazol height control and the transplant stage on the post-transplant growth for *Impatiens wallerana* pot plant. *European Journal of Horticultural Science* **72**, 193-197

Di Benedetto A, Klasman R (2007b) River waste as a potentially amendment for low quality *Sphagnum* peat. *European Journal of Horticultural Science* **72**, in press

Di Benedetto A, Molinari J (2007) Influence of river waste-based media on efficacy of paclobutrazol in inhibiting growth of *Petunia hybrida*. *International Journal of Agricultural Research* **2**, 289-295

Di Benedetto A, Molinari J, Boschi C, Klasman R, Benedicto D (2000) Plasticity of four annual flowering plants to different growing substrates. *AGROSUR (Chile)* **28**, 69-76 (in Spanish)

Di Benedetto A, Klasman R, Boschi C (2002) Evaluation of the use of Argentinean *Sphagnum* moss in three growing media for *Impatiens walleriana*. *AGROSUR (Chile)* **30**, 35-42 (in Spanish)

Di Benedetto A, Boschi C, Klasman R, Molinari J (2003) Ornamental bedding plant growth in different growing media. *Revista Brasileira de Horticultura Ornamental* **9**, 171-177 (in Spanish)

Di Benedetto A, Boschi C, Klasman R (2004) Use of river waste in growing media for growing ornamental herbaceous perennials. *Journal of Horticultural Science and Biotechnology* **79**, 119-124

Di Benedetto A, Klasman R, Boschi C (2006a) Argentinean peat: a poor substitute for Canadian *Sphagnum* peat for ornamental bedding plants. *European Journal of Horticultural Science* **71**, 69-72

Di Benedetto A, Petracchi JC, Marcella G, Montaron P, Chavez W (2006b) Evaluation of alternative substrates for bedding plants. *International Journal of Agricultural Research* **1**, 545-554

Erstad JLF, Gislerød HR (1994) Water uptake of cuttings and stem pieces as affected by different anaerobic conditions in the rooting medium. *Scientia Horticulturae* **58**, 151-160

Fonteno WC (1989) An approach to modelling air and water status of horticultural substrates. *Acta Horticulturae* **238**, 67-74

Frolking S, Roulet NT, Moore TR, Richard PJH, Lavoie M, Muller SD (2001) Modeling northern peatland decomposition and peat accumulation. *Ecosystems* **4**, 479-498

García Gómez A, Bernal MP, Roig A (2002) Growth of ornamental plants in two composts prepared from agroindustrial wastes. *Bioresource Technology* **83**, 81-87

Grimstad SO (1993) Influence of paclobutrazol residues on greenhouse-bench surfaces and the effect on growth and development of cucumber and tomato young plants. *Gartenbauwissenschaft* **58**, 59-63

Gruda N, Schnitzler WH (2004) Suitability of wood fiber substrate for production of vegetable transplants I. Physical properties of wood fiber substrates. *Scientia Horticulturae* **100**, 309-322

Guérin V, Lemaire F, Marfa O, Caceres R, Giuffrida F (2001) Growth of *Viburnum tinus* in peat-based and peat-substitute growing media. *Scientia Horticulturae* **89**, 129-142

Heiskanen J (1993) Variation in water retention characteristics of peat growth media used in tree nurseries. *Silvia Fennica* **27**, 77-97

Heiskanen J (1995a) Physical properties of two-component growth media based on *Sphagnum* peat and their implications for plant-available water and aeration. *Plant and Soil* **172**, 45-54

Heiskanen J (1995b) Water status of *Sphagnum* peat and a peat-perlite mixture in containers subjected to irrigation regimes. *HortScience* **30**, 281-284

Heiskanen J (1997) Air-filled porosity of eight growing media based on *Sphagnum* peat during drying from container capacity. *Acta Horticulturae* **450**, 277-286

Hicklenton PR, Rodd V, Warman PR (2001) The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. *Scientia Horticulturae* **91**, 365-378

King JA, Smith KA (1987) Gaseous diffusion through peat. *Journal of Soil Science* **38**, 173-177

Kleinbaum DG, Kupper LL (1978) *Applied Regression Analysis and Other Multivariable Methods*, Duxbury Press, North Situate, Massachusetts, USA, 588 pp

Knowles TC, Hipp BW, Hegemann MA (1993) Container medium and slow-release nitrogen fertilizer influence growth and quality of *Salvia farinacea*. *HortScience* **28**, 623-625

Ku CSM, Hershey DR (1992) Leachate electrical conductivity and growth of potted geranium with leaching fractions of 0 to 0.4. *Journal of the American Society for Horticultural Science* **117**, 893-897

Ku CSM, Hershey DR (1997) Growth response, nutrient leaching, and mass balance for potted poinsettia. I. Nitrogen. *Journal of the American Society for Horticultural Science* **122**, 452-458

Kuehny JS, Morales B (1998) Effects of salinity and alkalinity on pansy and impatiens in three different growing media. *Journal of Plant Nutrition* **21**, 1011-1023

Latimer JG, Oetting RD, Thomas PA (1995) Method of application affects

response of hollyhock to paclobutrazol. *HortScience* **30**, 626
Manning L-K, Tripepi RR, Campbell AG (1995) Suitability of composted bluegrass residues as an amendment in container media. *HortScience* **30**, 277-280
Marchese N, Di Benedetto A, Lavado R (2006) The possibilities of river waste and Argentinean peat as a plug growing media for *Verbena × hybrida*. *International Journal of Agricultural Research* **1**, 142-150
Marfa O, Lemaire F, Cáceres R, Giuffrida F, Guerin V (2002) Relationships between growing media fertility percolate composition and fertigation strategy in peat-substitute substrates used for growing ornamental shrubs. *Scientia Horticulturae* **94**, 309-321
Meerow AW (1994) Growth of two subtropical ornamentals using coir (coconut mesocarp pith) as a peat substitute. *HortScience* **29**, 1484-1486
Menzies NW, Aitken RL (1996) Evaluation of fly ash as a component of potting substrates. *Scientia Horticulturae* **67**, 87-99
Morvat JK, Dole JM, Cole JC (1998) Irrigation frequency and system affect poinsettia growth, water use, and runoff. *HortScience* **33**, 42-46
Nash VE, Laiche AJ (1981) Changes in the characteristics of potting media with time. *Communications in Soil Science and Plant Analysis* **12**, 1011-1020
Nelson PV (1994) Fertilization. In: Holcomb EJ (Ed) *Bedding Plants IV*, Ball Publishing, Batavia, Illinois, USA, pp 151-175
Nkongolo NV, Caron J (1999) Bark particle sizes and the modification of the physical properties of peat substrates. *Canadian Journal of Soil Science* **79**, 111-116
Noguera P, Abad M, Puchades R, Maquieira A, Noguera V (2003) Influence of particle size on physical and chemical properties of coconut coir dust as container medium. *Communications in Soil Science and Plant Analysis* **34**, 593-605
Papafotiou M, Asimakopoulou V, Kouvari P, Kovaeou I, Phsyhalou M, Lytra Y, Kargas G (2001a) Cotton gin trash compost as growing medium ingredient for the production of pot ornamentals. *Gartenbauwissenschaft* **66**, 229-232
Papafotiou M, Chronopoulos J, Kargas G, Voreakou M, Leonarditis N, Lagogiani O, Gazi S (2001b) Cotton gin trash compost and rice hulls as growing medium components for ornamentals. *Journal of Horticultural Science and Biotechnology* **76**, 431-435
Paquet JM, van de Werken H (1993) *In situ* determination of the water desorption characteristics of peat substrate. *Canadian Journal of Soil Science* **73**, 329-339
Perez-Murcia MD, Moreno-Caselles J, Moral R, Perez-Espinosa A, Paredes C, Rufete B (2005) Use of composted sewage sludge as horticultural growth media: effects on germination and trace element extraction. *Communications in Soil Science and Plant Analysis* **36**, 571-582
Prasad M, O'Shea J (1999) Relative breakdown of peat and non-peat growing media. *Acta Horticulturae* **481**, 121-128
Rader JS (1998) Petunia. In: Ball V (Ed) *Ball Redbook*, Ball Publishing, Batavia, Illinois, USA, pp 682-686
Ramos C, Agut A, Lidón AL (2002) Nitrate leaching in important crops of the Valencian community region (Spain). *Environmental Pollution* **118**, 215-223
Robertson RA (1993) Peat, horticulture and environment. *Biodiversity Conservation* **2**, 541-547
Ruter JM, van der Werken H (1991) Container design influences physical parameters of different media. *HortTechnology* **Oct/Dec**., 76-78
Salvador ED, Balas J (2006) Physical characteristics of soilless growing media: basis for the development of methods to formulate substrates for ornamental plants in Brazil. In: Teixeira da Silva JA (Ed) *Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues* (1st Edn, Vol III), Global Science Books, Isleworth, UK, pp 161-171
Schilstra AJ (2001) How sustainable is the use of peat for commercial energy production? *Ecological Economics* **39**, 285-293
Spomer AL (1975) Small soil containers as experimental tools: soil water relations. *Communications in Soil Science and Plant Analysis* **6**, 21-26
Topp GC, Zebchuk W (1979) The determination of soil-water desorption curves for soil cores. *Canadian Journal of Soil Science* **59**, 19-26
Topp GC, Davis JL, Annan AP (1980) Electromagnetic determination of soil water content: measurement in coaxial transmission lines. *Water Resource Research* **16**, 574-582
Verdonck O, Pennick R, de Boodt M (1983) The physical properties of different horticultural substances. *Acta Horticulturae* **150**, 155-160
Verhagen JBGM (1997) Characterisation of growing media or components for growing media to determine suitability for horticulture. *Acta Horticulturae* **450**, 363-364
Zubillaga MS, Lavado RS (2001) Biosolids compost as component of potting media for bedding plants. *Gartenbauwissenschaft* **66**, 304-309