



Alternative soilless media for growing *Petunia* × *hybrida* and *Impatiens wallerana*: Physical behavior, effect of fertilization and nitrate losses

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ABSTRACT

The use of alternative soilless media for the production of potted plants requires knowledge of their physical and chemical characteristics to result in the best conditions for plant growth. We investigated the use of alternative soilless media based on river waste and *Sphagnum* sp. and *Carex* sp. from Argentinean peatlands on *Petunia* × *hybrida* and *Impatiens wallerana* production at two fertilization levels (200 and 400 mg l⁻¹ N). River waste or 'temperate peat' is the name given to a material, resulting from the accumulation of aquatic plant residues under an anaerobic subtropical environment, which is dredged from river banks. Our results showed that alternative substrates based on river waste can be used to grow high quality plants. This result was not fully explained on the basis of established methods to evaluate substrate quality. Highly concentrated fertigation solution decreased the substrate quality parameters and plant growth. Nitrate leaching from the alternative substrates containing river waste was lower than the standard peat-based materials, which makes river waste desirable from a sustainable pot production system perspective. River waste and *Carex* peat are suitable alternatives to *Sphagnum* peat from the Northern Hemisphere.

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1. Introduction

Soilless substrates are used in horticulture for growing seedlings, plant propagation, and ornamental plant production. Annual ornamental plants require growing media with adequate water retention and aeration (Erstad and Gislerod, 1994) and a fertilization routine that ensures a continuous nutrient supply (Macz et al., 2001). The most common substrates for such cultures are prepared with *Sphagnum* peat from the Northern Hemisphere (Canada). *Sphagnum* peat base has a high physical and chemical stability and low degradation rate (Heiskanen, 1993, 1995; Al-laure-Leung et al., 1999). The increasing cost of high quality peat for horticultural use (Meerow, 1994) and its declining availability in the near future due to environmental constraints (Barkham, 1993; Frolking et al., 2001; Robertson, 1993) has prompted a search for alternative materials (García Gómez et al., 2002). Southern Hemisphere peat, from Australia (Handreck and Black, 1994) to Argentina (Di Benedetto et al., 2006a) does not seem to be a good substitute for *Sphagnum* peat from the Northern Hemisphere (i.e. from Canada). This is due to the low stability of aggregates in these peats. Previous research, however, has shown that river waste (Di Benedetto, 2007; Di Benedetto et al., 2004; Marchese et al., 2006)

can be used as an amendment for soilless media (Di Benedetto and Klasman, 2007). River waste or 'temperate peat' is the result of the accumulation of aquatic plant residues under an anaerobic subtropical environment and is dredged from lake and river banks.

The components of soilless substrates must have stable physical and chemical properties during plant cultivation. The bio-stability of alternative substrates varies considerably, which also affects the chemical properties of substrates, their management, and the growth of ornamental plants. The 'ideal substrate' proposed by Abad et al. (2001) had the following chemical characteristics: pH = 5.2–6.3; EC (dS m⁻¹) = 0.75–3.49; OM (%) >80; NO₃⁻-N (μg ml⁻¹) = 100–199; K⁺ (μg ml⁻¹) = 150–249; Na⁺ (μg ml⁻¹) = <115; Cl⁻ (μg ml⁻¹) = <180 and SO₄²⁻-S (μg ml⁻¹) = <960. Most new river waste- and low quality-based peat growing media do not fit with this 'ideal substrate' profile. Because of the lower stability of their physical and chemical properties they can not be analyzed exclusively using the conventional methods of analysis developed for high quality peat-based media (Verhagen, 1997; Di Benedetto et al., 2006b).

The marketability of potted plants is greatly influenced by the conditions of their production. The most important, among them, are related to substrate quality, drainage, irrigation, water quality and fertilization. Fertilization systems must supply nutrients according to plant needs. Nutrients for container grown plants are applied by injecting fertilizers into irrigation systems (liquid feeding). Nitrogen concentrations of these solutions are usually

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high, ranging from 200 to 500 mg l⁻¹ N (Nelson, 1994; Rader, 1998; James and van Iersel, 2001). Greenhouse container crop production requires frequent irrigation and high fertilization rates, which can result in contamination of ground and surface water (Lang and Pannuk, 1998). Nitrate pollution of groundwater is a serious problem in the European Union and in other countries (European Commission, 1999). The container plant industry is potentially an important source of nitrates but there is no exact information about its contribution to water contamination.

The use of alternative substrates for potted plant production requires knowledge of the physical and chemical characteristics of the substrates to result in the best conditions for plant growth. This study was carried out on alternative substrates based on river waste and *Sphagnum* and *Carex* peat from Argentinean peatlands and used to grow *Petunia × hybrida* and *Impatiens wallerana*. The aim was to study (i) physical reaction of substrates, (ii) the effect of two fertilization levels on crops and substrates, and (iii) the loss of nitrates by leaching.

2. Methods

Eight substrates were formulated using river waste, Argentinean *Sphagnum* and *Carex* peat, perlite and vermiculite. The formulae (wt/wt) were: Sp₁ (*Sphagnum* peat (80%) + Perlite (10%) + Vermiculite (10%)), Sp₂ (*Sphagnum* peat (70%) + Perlite (20%) + Vermiculite (10%)), SpRW₁ (*Sphagnum* peat (40%) + River waste (40%) + Perlite (10%) + Vermiculite (10%)), SpRW₂ (*Sphagnum* peat (35%) + River waste (35%) + Perlite (20%) + Vermiculite (10%)), Ca₁ (*Carex* peat (80%) + Perlite (10%) + Vermiculite (10%)), Ca₂ (*Carex* peat (70%) + Perlite (20%) + Vermiculite (10%)), CaRW₁ (*Carex* peat (40%) + River waste (40%) + Perlite (10%) + Vermiculite (10%)) and CaRW₂ (*Carex* peat (35%) + River waste (35%) + Perlite (20%) + Vermiculite (10%)).

A weekly fertilization of 200 or 400 mg l⁻¹ N (1 N:0.5P:1K:0.5Ca wt/wt) from transplant to sale stages was used. All nitrogen was as nitrate. A weekly fertilization volume of 75 ml pot⁻¹ was applied. Plants were watered daily as needed with a high quality tap water (pH: 6.64 and electrical conductivity of 0.486 dS m⁻¹). The fertilization solution for the 200 and 400 mg l⁻¹ N treatments showed a pH of 5.13 and 5.51 and an electrical conductivity of 2.41 dS m⁻¹ and 3.53 dS m⁻¹, respectively.

Petunia × hybrida 'Ultra' and *I. wallerana* 'Accent' seeds (Goldsmith Inc.) were germinated and grown in 200 cells plastic plug trays. When the fourth true leaf was developed, plants were transplanted into 1000 cm³ pots containing one of the eight different growing media mixtures tested. Twenty replicate pots (one plant per pot) per each media were used. Samples of each substrate were collected at transplanting and at the end of the experiment and physical properties were determined according to Fonteno (1996). A container of known volume was filled with the substrates. The standard pot used had holes in the bottom that were taped-closed and covered on the inside by nylon screens. The volume of substrates was recorded and water was added slowly until water reached the surface, substrate saturation, and the volume of added water was registered. The tape from the bottom of the container was then removed and the water drained and was collected for 60 min. The wet sample of substrate was weighed after 60 min, then dried at ambient temperature and reweighed.

The values obtained from the above procedure were used to calculate total porosity, air-filled porosity, and bulk density and container capacity using the following equations:

$$\text{Total porosity (\%v/v)} = \frac{(\text{wet weight} - \text{dry weight}) + \text{drained volume}}{\text{substrate volume}} \times 100 \quad (1)$$

$$\text{Air-filled porosity (\%v/v)} = \frac{\text{drained volume}}{\text{substrate volume}} \times 100 \quad (2)$$

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{dry weight}}{\text{substrate volume}} \times 100 \quad (3)$$

$$\text{Container capacity (\%v/v)} = \frac{(\text{wet weight} - \text{dry weight})}{\text{substrate volume}} \times 100 \quad (4)$$

Electrical conductivity (EC), pH, organic matter (OM) and nutrient concentrations (nitrogen, phosphorus, potassium, calcium, magnesium and sodium) were determined on all substrates at transplanting and at the end of the experiment, using standard procedures (Sparks et al., 1996). Chemical analyses were performed in duplicate (samples included five pots per treatment). Electrical conductivity, pH, and nitrate concentration by colorimetry after Daniel and Marban (1989) were determined on five samples of leachate from each pot. Five leachate samples were collected from each treatment at both day 10 and day 50.

Crops were harvested after ten weeks, dried at 80 °C for 48 h and weighed to determine the dry aerial and root biomass (twenty replicates).

The experimental design was a randomized complete block with 20 single-pot replications of each treatment combination (media × fertility). Data were subjected to analysis of variance and means were separated by Tukey tests ($P < 0.05$). 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 of the regression straight lines from Kleinbaum and Kupper (1978).

3. Results

3.1. Physical and chemical characteristics of the media

Initial total porosity was significantly higher for substrates with the highest proportion of *Sphagnum* (Sp₁) and *Carex* (Ca₁) peat (Table 1). Total porosity decreased between the beginning and the end of the experiment, but air-filled porosity and container capacity did not show a defined pattern. Bulk density was significantly higher when river waste was used, especially when mixed with *Carex* peat.

Media pH appeared to decrease from the beginning to the end of the experiments in Sp₁, Sp₂, Ca₁ and Ca₂ with no change in pH for the other growing media tested (Table 2). Substrates containing river waste tended to have higher electrical conductivity. After irrigation, electrical conductivity increased in treatments Sp₁, Sp₂, Ca₁ and Ca₂ but decreased in all treatments when river waste was added to the substrate (SpRW₁, SpRW₂, CaRW₁ and CaRW₂). Organic matter percentages were lower when river waste was included in the substrate but showed significant differences ($P < 0.05$) during the experiments. Both treatments with river waste showed an initial very high content of phosphorus.

3.2. Leachates

The pH values of leached solutions over time did not show changes between substrates or fertilization level; electrical conductivity (EC) showed a general tendency to decrease from day 10 to day 50. Higher EC values were found in treatments with river waste (Table 3). Nitrate levels in leachates were less than 5.0 mg l⁻¹ for most of the substrates tested and in some cases around 1.0 mg l⁻¹ (Table 4). Nitrate concentrations in the leachate solutions showed significant difference among substrates. Considering the quantity of nitrate leached (nitrate concentra-

Table 1

Physical properties of eight growing media at two fertilization levels

Substrate	Porosity (%)			Air-filled porosity (%)			Container capacity (%)			Bulk density (g cm ⁻³)		
	Initial	End		Initial	End		Initial	End		Initial	End	
		200 mg l ⁻¹	400 mg l ⁻¹		200 mg l ⁻¹	400 mg l ⁻¹		200 mg l ⁻¹	400 mg l ⁻¹		200 mg l ⁻¹	400 mg l ⁻¹
Sp ₁	92 Aa	94.0 a	81.3 b	30.1 Aa	30.2 a	23.7 b	56.0 Ba	53.4 a	39.0 b	0.15 CDa	0.18 a	0.20 a
Sp ₂	84 BCa	77.2 a	60.3 b	22.3 Ba	24.0 a	21.1 a	52.2 Ba	41.0 b	26.6 c	0.23 Cb	0.32 a	0.38 a
SpRW ₁	76 Cb	82.8 a	72.5 b	19.7 Ba	21.1 a	20.5 a	49.6 Ba	39.3 b	42.3 b	0.30 Cb	0.40 a	0.47 a
SpRW ₂	80 BCa	81.5 a	75.0 b	29.5 Aa	23.0 a	25.6 a	40.1 Ca	45.8 a	39.6 a	0.23 Ca	0.26 a	0.28 a
Ca ₁	89 ABa	90.4 a	84.1 b	28.5 Aa	24.7 a	26.1 a	62.5 Aa	42.1 b	38.4 b	0.16 CDa	0.21 a	0.23 a
Ca ₂	80 BCa	79.1 a	81.1 a	14.3 Cb	19.6 a	22.5 a	53.0 Ba	30.4 b	37.9 b	0.29 Ca	0.34 a	0.38 a
CaRW ₁	67 Db	78.8 a	68.8 b	11.8 Cb	25.4 a	22.8 a	47.0 Ba	42.6 a	33.6 b	0.43 Bb	0.51 a	0.56 a
CaRW ₂	77 Ca	69.1 b	61.9 c	17.3 Ca	21.7 a	23.3 a	40.2 Ca	32.6 a	30.6 b	0.54 Aa	0.49 b	0.59 a

Different capital letters indicate statistically significant differences ($p \leq 0.05$) between growing media while different lower case letters indicate statistically differences ($p \leq 0.05$) between fertilization routines. Mean of five replicates.

Sp₁ (*Sphagnum* peat (80%) + Perlite (10%) + Vermiculite (10%)), Sp₂ (*Sphagnum* peat (70%) + Perlite (20%) + Vermiculite (10%)), SpRW₁ (*Sphagnum* peat (40%) + River waste (40%) + Perlite (10%) + Vermiculite (10%)), SpRW₂ (*Sphagnum* peat (35%) + River waste (35%) + Perlite (20%) + Vermiculite (10%)), Ca₁ (*Carex* peat (80%) + Perlite (10%) + Vermiculite (10%)), Ca₂ (*Carex* peat (70%) + Perlite (20%) + Vermiculite (10%)), CaRW₁ (*Carex* peat (40%) + River Waste (40%) + Perlite (10%) + Vermiculite (10%)) and CaRW₂ (*Carex* peat (35%) + River waste (35%) + Perlite (20%) + Vermiculite (10%)).

Table 2

Chemical properties of eight growing media at two fertilization levels

Substrate	pH	EC (ds m ⁻¹)	OM (%)	N (%)	P (mg l ⁻¹)	K (meq l ⁻¹)
<i>Sp₁</i>						
Initial	6.33	0.21	68.6	0.74	3.56	1.29
200	5.88	0.51	72.4	0.76	48.87	0.90
400	5.47	1.26	73.1	0.85	41.40	0.77
<i>Sp₂</i>						
Initial	7.24	0.21	70.5	0.89	4.12	1.24
200	5.73	0.81	69.0	0.92	33.63	0.69
400	5.68	0.85	74.1	0.69	47.61	1.07
<i>SpRW₁</i>						
Initial	6.61	4.05	55.7	0.87	82.55	2.20
200	6.55	2.13	57.7	0.81	128.51	1.30
400	6.68	1.29	62.6	0.77	140.22	1.09
<i>SpRW₂</i>						
Initial	6.74	4.05	51.0	0.87	93.44	2.02
200	6.65	1.89	60.6	0.75	89.01	1.11
400	6.43	1.14	61.5	0.72	146.47	1.01
<i>Ca₁</i>						
Initial	6.35	0.34	67.9	0.71	4.04	1.31
200	5.92	0.59	72.2	0.84	65.21	0.93
400	5.84	0.67	73.3	0.81	50.45	1.05
<i>Ca₂</i>						
Initial	6.84	0.32	64.00	0.56	4.04	1.17
200	6.35	0.44	65.16	0.86	110.16	0.79
400	5.89	0.80	70.74	0.76	106.85	0.89
<i>CaRW₁</i>						
Initial	6.92	4.12	57.7	0.65	119.55	1.78
200	6.84	1.23	63.9	0.80	160.91	0.99
400	6.72	1.10	69.1	0.72	159.70	1.01
<i>CaRW₂</i>						
Initial	6.95	3.23	54.4	0.78	117.91	2.20
200	6.67	1.38	66.5	0.77	154.88	1.11
400	6.69	1.72	64.4	0.87	191.78	1.01

Mean of two replicates. Substrate abbreviations as in Table 1.

tion \times leachate volume), losses of nitrates increased as the experiments proceeded and doses of 400 mg l⁻¹ N lost larger quantities of nitrates. On the other hand, substrates with river waste lost less nitrate (Table 5).

Ten days after the experiment started, EC and nitrate concentration showed a high significant correlation ($\text{Pr} > F = 0.005$; $r = 0.97$ for 200 mg l⁻¹ treatment and $r = 0.85$ for 400 mg l⁻¹ treatment). Fifty days later there was a weak correlation between EC and nitrate concentration ($r = 0.41$ and $r = 0.57$ for 200 and 400 mg l⁻¹ treatments, respectively; $\text{Pr} > F = 0.005$; data not shown).

3.3. Plant growth

The highest dry weight of *Petunia \times hybrida* at harvest (65 days from transplant) was found in plants grown in *Carex* peat plus river waste (CaRW₁) and fertilized with 200 mg l⁻¹ N (Fig. 1; $\text{Pr} > F = 0.005$). Plants grown in some substrates fertilized with 400 mg l⁻¹ N showed the least dry weight. In general (Fig. 1), plants grown in all substrates containing river waste had the best performance ($\text{Pr} > F = 0.005$ for comparison of river waste vs. others). Root and aerial biomass dry weight results were parallel. There were very low correlations between dry weight and total porosity and air-filled porosity however ($r = 0.01$ – 0.18 ; data not shown).

The highest total dry weight of *I. wallerana* was found when *Carex* peat was used (Ca₂) but the worst results were found when *Sphagnum* peat-based media was used (Fig. 2) ($\text{Pr} > F = 0.005$). In this case, the highest dry weight was found in roots rather than shoots. Shoot dry weight showed no significant differences among treatments ($\text{Pr} > F = 0.005$). Under a high fertilization routine the root growth was in general lower than with the low fertilization routine. This fact contributed to a significant decrease in total dry weight with high fertilization for all the substrates tested ($\text{Pr} > F = 0.005$). Correlations between dry weight and physical properties (total porosity and air-filled porosity) showed lower correlations than in the case of *Petunia \times hybrida* ($r = 0.01$ – 0.18 ; data not shown).

4. Discussion

In the production of potted plants the most important criteria for assessing the quality of substrates are their initial physical and chemical properties and their stability during the crop growth cycle. The alternative substrate tested in our experiments did not fit the profile for an 'ideal substrate' described by Abad et al. (2001). For instance, the alternative substrates we tested had high pH and low organic matter and low potassium contents. Other nutrients (calcium, magnesium and sodium) were in low concentration and exhibited little change between the initial and final concentration after the two fertilization routines (data not shown). As was previously indicated (Di Benedetto et al., 2006b) the changes in substrate porosity could be associated with the lower stability of river waste and Argentinean *Sphagnum* peat compared to high quality Canadian peat.

Even though the alternative media did not measure up to the 'ideal' substrate criteria, we showed that it was possible to obtain high quality *Petunia \times hybrida* and *I. wallerana* plants with a

Table 3

Changes in pH and electrical conductivity in the leached solution from pots of eight growing media and two fertilization level at the beginning (day 10) and the end (day 50) of the experiment

Substrate	pH				Electrical conductivity (dS m ⁻¹)			
	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 ₁	5.9	6.9	6.5	6.7	1.2	1.1	1.4	1.6
Sp ₂	6.6	7.3	6.8	6.7	1.4	1.4	1.4	1.6
SpRW ₁	6.7	7.4	6.5	7.0	2.6	1.6	2.3	1.7
SpRW ₂	6.0	6.8	6.0	6.5	2.2	1.1	2.1	1.5
Ca ₁	6.5	6.8	6.6	6.1	1.2	1.0	1.3	1.6
Ca ₂	7.1	7.6	6.5	7.0	1.6	1.1	1.5	1.9
CaRW ₁	7.1	7.5	6.7	7.2	2.8	2.2	2.9	2.4
CaRW ₂	7.0	7.4	6.7	6.8	2.8	2.0	2.6	2.3
LSD	2.34	2.12	2.18	2.03	0.72	0.52	0.44	0.64

The values are the average of both crop plants, because there were no significant differences between leachates from *Petunia × hybrida* or *Impatiens wallerana* ($P < 0.05$). Mean of 10 replicates, five from each of the two crops. Least significant difference (LSD) were indicated. Substrate abbreviations as in Table 1.

Table 4

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

Substrate	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 ₁	5.0	2.4	3.4	2.9	1.4	3.9	1.3	6.1
Sp ₂	3.2	2.5	2.7	2.1	1.1	4.2	1.2	4.9
SpRW ₁	1.6	1.5	2.7	1.4	0.6	3.0	0.8	2.8
SpRW ₂	1.8	0.5	2.0	2.2	0.7	1.0	0.7	4.6
Ca ₁	5.0	3.0	4.7	3.6	1.5	5.7	1.8	7.6
Ca ₂	3.7	1.2	3.7	4.4	1.1	2.4	1.4	10.2
CaRW ₁	1.2	1.3	1.1	1.5	0.5	2.9	0.4	3.0
CaRW ₂	2.2	1.0	2.0	1.1	0.9	2.2	0.9	2.6
LSD	1.06	0.86	0.80	0.78	0.46	1.21	0.32	1.88

The values are the average of both crop plants, because there were no significant differences between leachates from *Petunia × hybrida* or *Impatiens wallerana* ($P < 0.05$). Mean of 10 replicates, five from each of the two crops. Least significant difference (LSD) were indicated. Substrate abbreviations as in Table 1.

Table 5

Equations for estimating nitrate leaching ($\text{Pr} > F = 0.005$) 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

soilless media containing Argentinean *Carex* peat and river waste (Figs. 1 and 2) at relatively low fertilization levels (200 mg l⁻¹ N). These results agree with those of Verhagen (1997) and Di Benedetto et al. (2006b) and indicate that the evaluation of alternative substrates for use in horticulture demands a new analytical approach along with revised 'ideal' substrate criteria.

River waste has been indicated as a potential substitute for Northern Hemisphere *Sphagnum* peat (Di Benedetto, 2007; Di Benedetto et al., 2004) and an amendment for low quality *Sphagnum* peat (Di Benedetto and Klasman, 2007). An earlier report (Di Benedetto et al., 2006a), however, showed that Argentinean *Sphagnum* peat would be a poor substitute for ornamental plants. Our results for *Petunia × hybrida* and *I. wallerana* (Figs. 1 and 2) are in agreement with the available information from Di Benedetto et al. (2006b). Argentinean *Carex* peat, a material recently used for pot plant production would show a better response than Argentinean *Sphagnum* peat.

The most important physical factors affecting plant growth are water retention and aeration of the substrate. These not only determine the availability of water and air, but also affect the thermal

properties, biological activity and mineral availability of the medium (Klock, 1997). Chong et al. (1994), using mushroom compost as a growing media for Weigela, also found that growth was a function of total pore space and not of chemical properties as assessed by electrical conductivity value at the start of the experiment. Chemical properties also play a major role because they govern the efficiency of nutrient supply and influence the environmental balance both during and after cultivation (Noguera et al., 2003). The low correlation (Table 5) between plant dry weight and total porosity, air-filled porosity and other substrate parameters (from data in Figs. 1 and 2 and Tables 1 and 2) 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 analytical methodology to be developed must show not only the initial and final physical and chemical attributes of the alternative growing media but also the changes caused by root and shoot growth. Finally, the pollution consequences (e.g. nitrate leaching characteristics) and plant growth must be considered when evaluating a new media.

The response of *I. wallerana* to changes in substrate formulations under relatively low nutrient fertilization was greater than for *Petunia × hybrida*. There were significant differences in dry weight accumulation between substrates based on river waste, *Sphagnum* and *Carex* peat (Figs. 1 and 2). On other hand, main root length and root thickness under the two fertilization routines were similar in all the substrate tested for *Petunia × hybrida* and *I. wallerana* (data not shown).

Bedding plant fertilizer recommendations are usually high (Nelson, 1994; Rader, 1998). However, our results showed that a high N

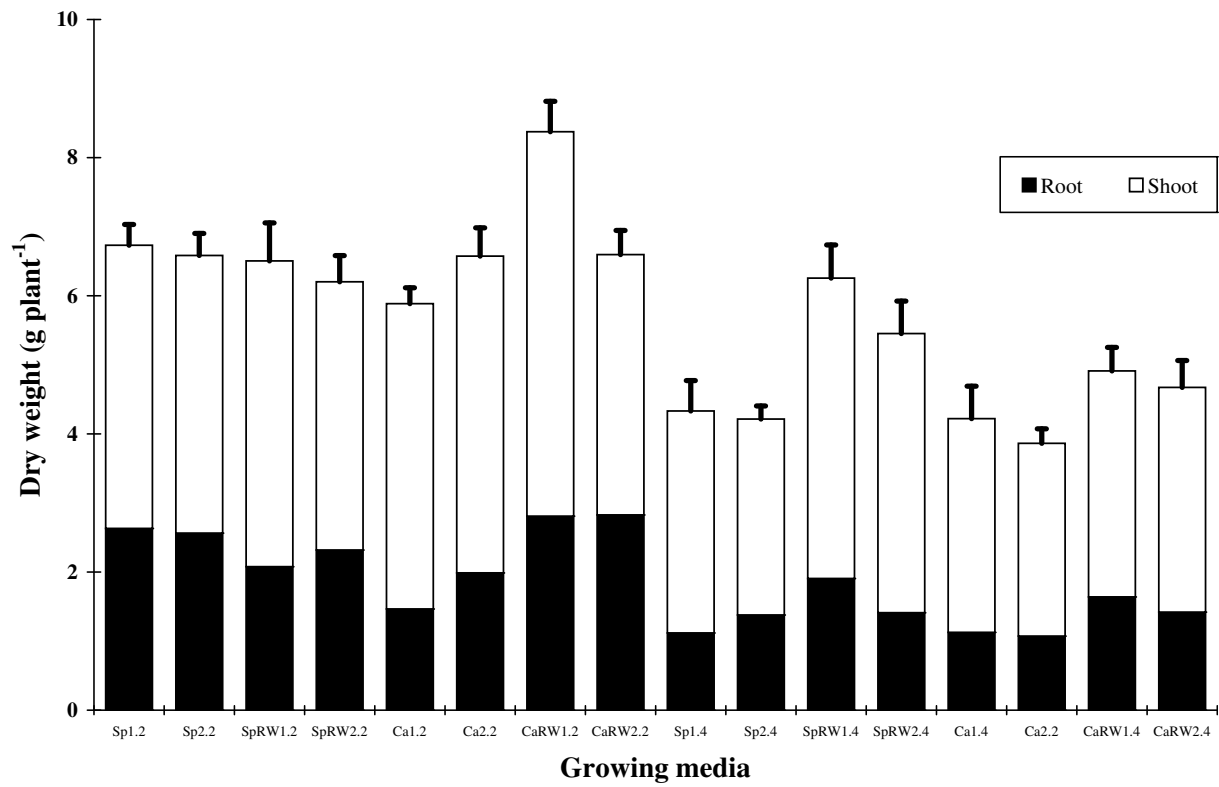


Fig. 1. Dry weight (g plant⁻¹) at the end of the experiment (sale stage) of *Petunia × hybrida* plants grown in eight growing media at 200 mg l⁻¹ N (0.2) or 400 mg l⁻¹ N (0.4) fertilization level. Mean of 20 replicates + SEM.

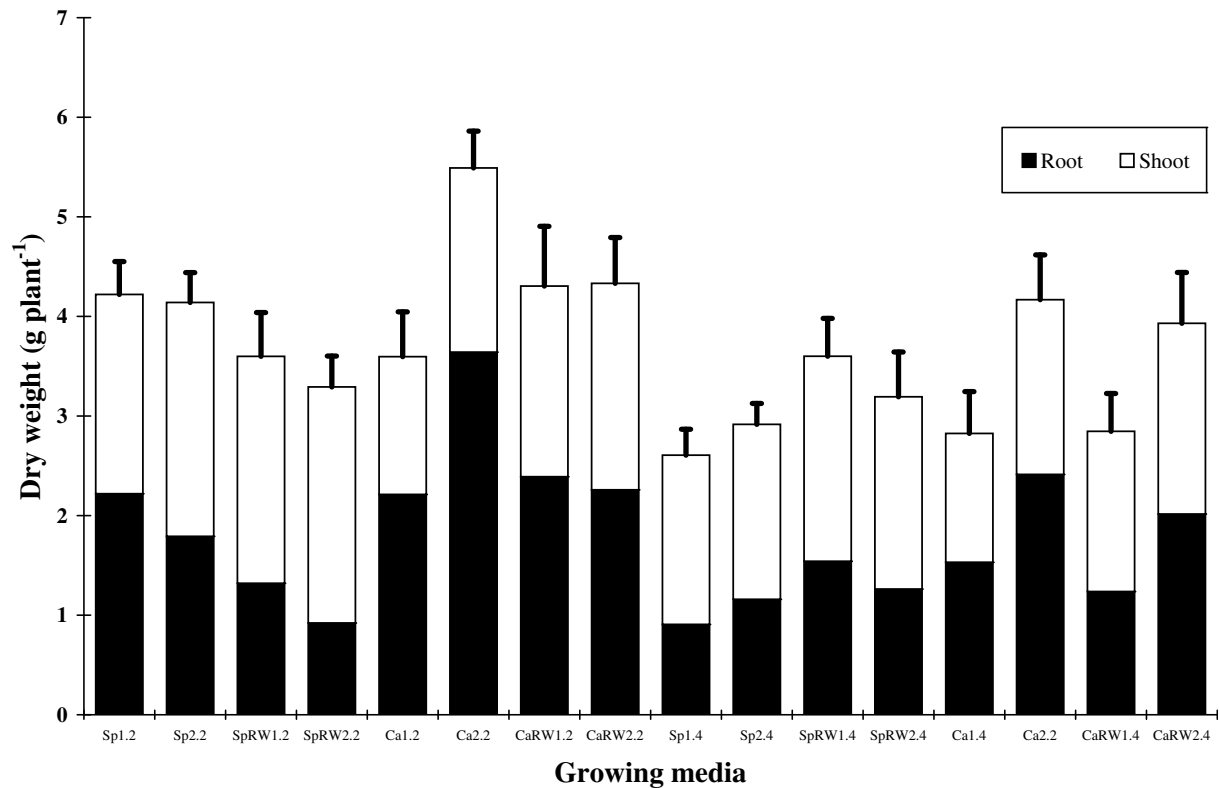


Fig. 2. Dry weight (g plant⁻¹) at the end of the experiment (sale stage) of *Impatiens wallerana* plants grown in eight growing media at 200 mg l⁻¹ N (0.2) or 400 mg l⁻¹ N (0.4) fertilizations levels. Mean of 20 replicates + SEM.

fertigation decreased the dry weight of *Petunia* × *hybrida* and *I. wallerana* in all alternative growing media tested. The lowest *Petunia* × *hybrida* and *I. wallerana* growth could be associated with a change in media chemical properties. However, there were only minor changes in pH and electrical conductivity (Table 3). The EC of leachates was not influenced by nitrates only. At the beginning of the experiments mostly chlorides were leached which caused a negative correlation between EC and nitrate concentrations (data not shown). On other hand the lower the nutrient losses from river waste-based substrates, the higher nutrient concentration in both substrate and plant tissues. This could be the reason why the best plant growth was found with the lowest fertilization rate.

The amounts of naturally occurring available nutrients in Argentinean *Sphagnum* and *Carex* peat were low. On the other hand, the phosphorus contents in river waste were extremely high (Table 2), affecting the recommended N:P:K:Ca ratio. Thus, fertilizers added to substrates with river waste must contain lower P concentrations than those used for other organic horticultural substrates.

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 salinization and its damaging consequences. However, excessive leaching is undesirable because it may contaminate the environment with fertilizers (Ku and Hershey, 1997). Our results showed that the eight alternative substrates tested lost different amounts of NO_3^- but the substrates with river waste lost the least NO_3^- . The nitrogen recovered by plants estimated by multiplying total biomass by N concentration (data not shown), 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 nitrate losses estimated through leachate analysis. Losses other than nitrate leaching or nitrogen retained in substrates can be the main reasons for some differences. Here again, substrates with river waste appeared to lose less nitrate (Tables 4 and 5). This experiment suggests that leaching of nitrogen from container plants can be minimized and the risk of environmental pollution can be avoided by using this alternative growing media.

5. Conclusions

Alternative substrates in suitable mixtures can support the growth of high quality plants. This result is not exclusively explained by established methods to evaluate substrate quality based only on physical and chemical characteristics; the pollution consequences (e.g. nitrate leaching) and plant growth must be considered too. This emphasizes the need for new knowledge about alternative substrates in order to offer the best conditions for plant growth. High concentration fertigation solution decreased substrate quality parameters and plant growth. Finally, nitrate leaching from the substrates containing river waste was lower than that of high quality peat, indicating a potential contribution of this new substitute for sustainable pot production systems.

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