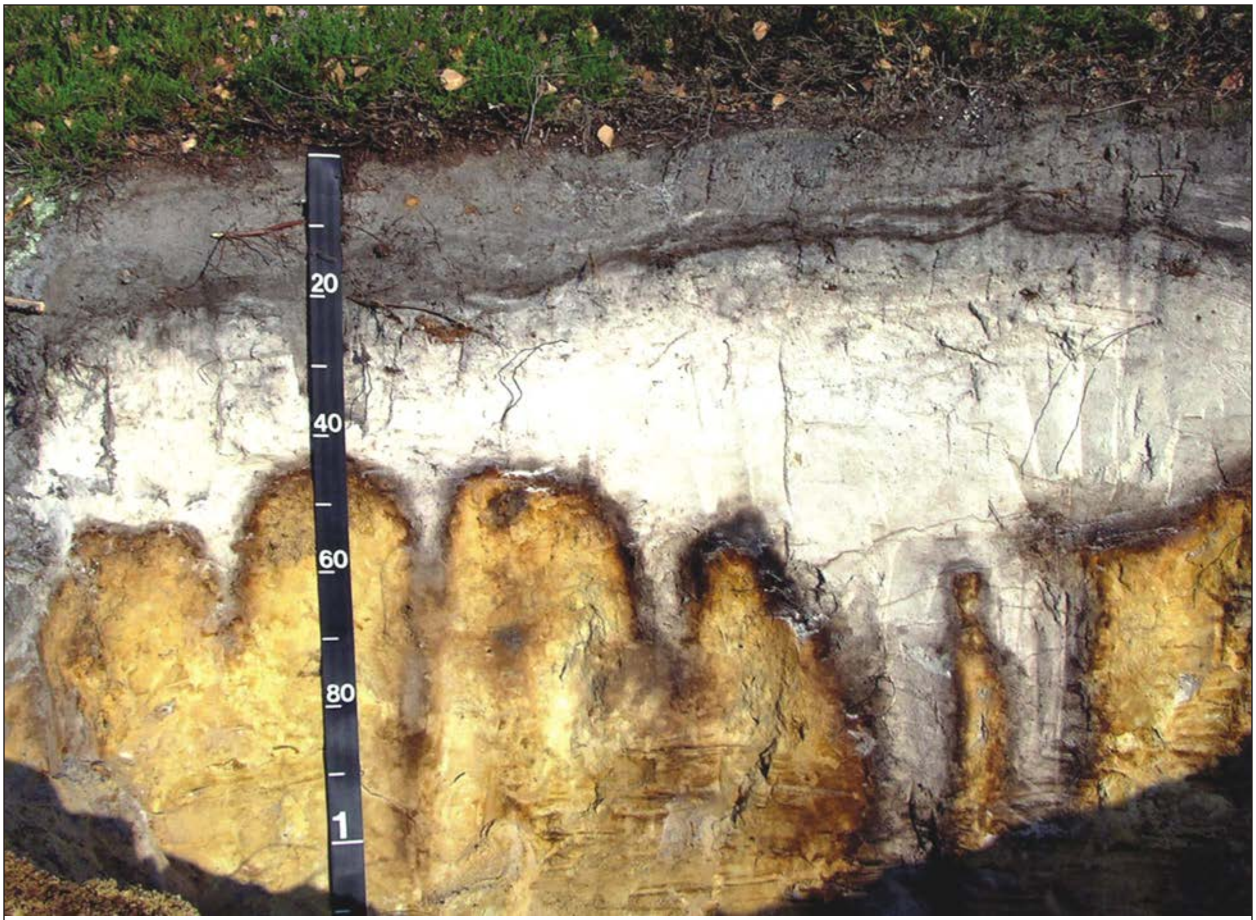

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Effects of Fresh and Composted Organic Wastes on Media Physical Properties and Growth of Three Ornamental Species

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Abstract: Amending growing media with organic wastes may improve physical properties and enhance plant growth. We studied the physical properties of peat-based media amended with organic wastes and related these properties to the growth of three ornamental species. Four rates (55, 45, 35 and 25% v/v) of peat were mixed to four rates (10, 20, 30 and 40% v/v) of fresh and composted organic wastes and to a single rate (35%) of perlite. Wastes were both Fresh and Composted Bio-Filter (FBF and CBF), Sewage Sludge (FSS and CSS) and De-Inked Paper Sludge (FDP and CDP). *Tagetes patula*, *Calceolaria herbeohybrida* and *Impatiens wallerana* were grown in the media for four months. Physical properties of the media studied were saturated hydraulic conductivity (Ks), air-filled porosity (f_a), relative gas diffusivity coefficient (D_s/D_0) and pore tortuosity (τ). Ks ($p = 0.0001$) and D_s/D_0 ($p = 0.0035$) increased while τ ($p = 0.01$) linearly decreased with increasing rate of organic wastes. f_a was not significantly affected. Plant dry weight (PDW) of *Impatiens wallerana* ($p = 0.0001$), *Tagetes patula* ($p = 0.0018$) and *Calceolaria herbeohybrida* ($p = 0.0001$) linearly decreased with increasing rate of organic wastes. PDW was significantly correlated with τ and D_s/D_0 with correlation coefficients (r) ranging form 0.70 to 0.90. These results suggest that measurements of pore space characteristics (τ and D_s/D_0) in top of storage properties (water and air contents) of media may be useful in understanding the relationship between plant growth and the physical properties of growing media.

Key words: Organic waste, media physical properties, ornamental species, plant dry weight

INTRODUCTION

Understanding the relationship between plant growth and the physical conditions of the root zone requires an assessment of the current variations in the storage and supply capability of the substrate (Nkongolo and Caron, 2006). In fact, the physical properties of growing media become more and more important for optimal plant growth. As they cannot be changed during the growing period, these properties should be optimal from the beginning (Verdonck and Demeyer, 2004). Improvements in air storage and water supply capability of horticultural plants media have often been attributed to component particle size (Caron *et al*., 2001), container size (Kenneth *et al*., 1987), substrate

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manufacturing (Paquet *et al*., 1993). Milks *et al*. (1989) suggested that handling and container geometry may have more effect on media physical properties than mixes themselves. Many organic wastes with a high organic matter content such as animal manure (Haynes and Naidu, 1998), sewage sludge (Albiach *et al*., 2001), city refuse (Giusquiani *et al*., 1995; Eriksen *et al*., 1999), compost (Tejada and Gonzalez, 2005), crop wastes (De Neve and Hofman, 2000) and industrial byproducts (Madejon *et al*., 2001; Tejada and Gonzalez, 2004) have been applied as soil and container media amendments. Dede *et al*. (2006) used peat, hazelnut husk and maize straw as support materials and municipal solid waste compost and poultry manure as fertilizer supplements in container production of Impatiens. In container studies, depending upon the type and rate of organic material, air and water supply capability was decreased (Bugbee *et al*., 1991), increased (Warren and Fonteno, 1993) or unaffected (Caron *et al*., 2001). Differential plant growth responses have also been reported as the result of amending media with organic wastes. Chong and Cline (1993) reported that media with more than one-third by volume of paper mill sludge depressed growth of four ornamentals. Nkongolo *et al*. (2000) found that the growth of Geranium was either linearly or quadratically decreased as the rate of organic waste increased in the media. Assessments of the physical conditions of the root zone focuses on storage (Air-filled porosity and water holding capacity) characteristics which in many cases have hardly been related to plant response. Information is therefore lacking on exchanges properties of the root zone. Yet, it is commonly recognized that gas exchange rate and dynamics is more important than storage alone in providing oxygen to plant roots (Caron and Nkongolo, 2004). The objectives of this study were therefore (1) to evaluate the physical properties container substrates resulting from the amendment with both fresh and composted forms of the same waste and (2) to relate plant growth to the physical properties growing media.

MATERIAL AND METHODS

Growing Media Preparation

Greenhouse experiments were conducted in winter and summer of 1997 at the Horticultural Research Center at Laval University, Ste-Foy, Québec, Canada. Four rates (10, 20, 30 and 40% v/v) of each of 6 types of organic wastes combined to four rates (55, 45, 35 and 25% v/v) of peat and to a single rate (35% v/v) of perlite (Table 1). Organic wastes were both fresh and composted bio-filter (Les Tourbières Premier, Rivière du Loup, Québec), fresh and composted sewage sludge (Fafard and Frères, Bonaventure, Québec) and fresh and composted de-inked paper (Les Compost du Québec, Saint Henri, Québec). Chemical composition of these wastes are given in Table 2. Regular greenhouse container, 11.15 cm in diameter by 11 cm deep were filled with each of the 24 peat/organic waste/perlite media. Containers with media were immersed in degassed tap water and allowed to saturate. Little Devil Fire (*Tagetes patula*), Anytime Mix (*Calceolaria herbeohybrida*) and Accent Coral (*Impatiens wallerana*) seeds were sown in multicellular plates of 200 units each filled with commercial potting mix (PRO-MIX PG ®, Les Tourbières Premier, Rivière du Loup, Québec). Substrate temperature was maintained at 22±2°C with heating cables during the first two weeks after sowing. Seedlings were irrigated and fertilized as the need occurred with a solution of 150, 36, 168, 120 and 28 ppm of N, P, K, Ca and Mg, respectively. They were also supplied with a solution of micronutrients containing 0.75, 0.64, 0.22, 0.20, 0.07 and 0.03 ppm of Fe, Mn, Zn, B, Mo and Cu, respectively. A month after sowing, plantlets-seedlings of about the same height, size and appearance were selected and transferred into 11.15 cm diameter pot (type Ultra ®, Kord Products Ltd., Ontario) filled with substrate made of peat, perlite and organic wastes as described above. Plantlets-seedlings were subirrigated and waste water was recycled. Each two or three days, plantlets were provided with a nutritive solution made of 100, 30, 106 and 35 ppm of N, P, K, Ca and Mg successively. Micronutrients solution was made of 2.0, 0.75, 0.30, 0.25, 0.046 and 0.13 ppm of Fe, Mn, Zn, B, Mo

Table 1: Composition of growing media

Perlite	35	35	35	35
Peat	55	45	35	25
Organic waste	10	20	30	40

Table 2: Chemical properties of different types of wastes

Parameters	FBF	CBF	FSS	CSS	FDP	CDP
Organic matter (%)	90.90	79.30	76.80	89.80	72.30	67.50
Dry weight (DW) (%)	24.70	26.20	31.10	38.30	40.90	40.30
N (Ammonia) (mg N kg^{-1} DM)	81.00	109.00	1324.00	2450.00	9.00	23.00
Nitrites, Nitrates (mg N kg^{-1} DM)	739.00	4120.00	96.00	10.00	19.00	830.00
P (mg P kg^{-1} DM)	59.00	5040.00	3150.00	3500.00	50.00	1190.00
K (mg K kg^{-1} DM)	170.00	9620.00	7750.00	8900.00	97.00	272.00
Ca (mg Ca kg^{-1} DM)	11100.00	10900.00	8410.00	5520.00	7960.00	111000.00
Mg (mg Mg kg^{-1} DM)	100.00	2980.00	1980.00	1990.00	357.00	1100.00
Na (mg Na kg^{-1} DM)	460.00	2550.00	1700.00	1930.00	1150.00	2130.00
pH	5.27	4.38	6.42	6.09	9.11	7.45
Salinity (mS)	1.26	6.67	3.75	3.82	0.17	1.73
CEC (meq/100g)	96.40	83.10	58.10	68.10	8.50	21.10
C/N ratio (%)	52.60	45.80	43.10	51.50	41.70	40.70
Cd (mg Cd kg^{-1} DM)	0.60	0.80	1.10	0.80	ND	ND
Co (mg Co kg^{-1} DM)	2.00	3.00	4.00	5.00	5.00	3.00
Fe (mg Fe kg^{-1} DM)	1850.00	3190.00	6720.00	1310.00	1050.00	1960.00
Mn (mg Mn kg^{-1} DM)	161.00	321.00	575.00	339.00	22.00	115.00
Ni (mg Ni kg^{-1} DM)	9.00	35.00	96.00	38.00	13.00	15.00
Pb (mg Pb kg^{-1} DM)	7.00	8.00	54.00	7.00	24.00	24.00
Zn (mg Zn kg^{-1} DM)	47.00	ND	92.00	167.00	31.00	158.00
Cu (mg Cu kg^{-1} DM)	ND	ND	159.00	ND	93.00	196.00

ND = Not Determined, DM = Dry mass basis

and Cu. Greenhouse conditions were standardized for commercial production. Air temperature was maintained at 22+2/18+2°C day/night. Mist fans were used to maintain relative humidity of 90%. Sixteen hours of photoperiod were maintained in the greenhouse. A thermal shedding tissue LS16 ® which gave 65% of shading was used between 11: 00 am and 15:00 pm during sunny days. These conditions were maintained throughout the experiment. Data on plant height and width were regularly collected and served to monitor plant growth. After four months of growth, plants were removed and media were subjected to in-situ measurements of physical properties.

Measurements of the Physical Properties of Media

Physical properties of the media studied were saturated hydraulic conductivity, air-filled porosity relative gas diffusivity coefficient and pore tortuosity. Details on measurements of these properties were given in Nkongolo and Caron (2006) and Caron and Nkongolo (2004).

Air-filled porosity air-filled porosity is the portion of the pore space filled with air (air space). It was calculated by difference between volumetric water content at saturation (0 Kpa) and that at container capacity (-0.5 Kpa). Time domain reflectometry was used to measure water content at both potentials.

Saturated hydraulic conductivity is the speed at which water is freed from the media when saturated. A Côté infiltrometer was used to measure the water flow in each pot under a constant pressure head (3 cm of water). A nylon mesh (0.15 cm) was placed on the surface of media to prevent light particles from floating and plugging the Mariotte bottle's opening during the flow. The water flux was measured after steady state had been reached and the final height of the substrate determined thereafter.

Pore tortuosity is defined as the ratio of the average capillary tube length, L_e, to the length of the porous media (soil sample), L, along the major flow (diffusion) axis, in a tortuous (sinuous) capillary tube of uniform diameter.

Relative gas diffusivity coefficient is the ratio between the gas diffusion coefficient in media to the gas diffusion coefficient in air. After physical parameters measurements, Little Devil Fire (*Tagetes patula*), Accent Coral (*Impatiens wallerana*) and Anytime Mix (*Calceolaria herbeohybrida*) roots were removed from the media, washed, oven dried and weighted.

Statistical Analysis

Analysis of variance was conducted using Statistix for windows, version 8.0 (Analytical software, FL). A completely randomized block design was used with 6 organic waste type (T) ×4 rate of application (R) × 3 plant species × 3 replications for a total of 216 observations. Regression analysis was performed using Microsoft Excel.

RESULTS AND DISCUSSION

Chemical Properties of Organic Wastes

The chemical properties of organic wastes used in this study are showed in Table 2. Fresh bio-filter and deinked paper had more organic matter content and higher pH as compared to their respective composted forms. However, salinity and all major nutrients (N, P, K, Mg, Ca) were higher in the composted forms of organic wastes.

Effects of Organic Waste on the Physical Properties of Media

Saturated hydraulic conductivity was significantly affected by both the type ($p = 0.0001$) and rate of application ($p = 0.0001$) of organic waste. However, the pore tortuosity factor ($p = 0.0001$) and the relative gas diffusion coefficient ($p = 0.0035$) were only affected by organic waste rate of application. Air-filled porosity did neither respond to organic waste type nor to their rate of application. Similar results were reported by Caron *et al*. (2001) who measured the aeration properties of several mixes made of a 1:1 and 2:1 fine peat and wood bark in pots 5 and 17 weeks after potting. They found that air filled porosity remained relatively unaffected by smaller bark fragment sizes, but for the coarser bark size, the air filled pore space doubled. However, these results are opposed to those reported by Bowman *et al*. (1994) who used ground tire automobiles as container soil amendment. They found that amendment with the coarse material decreased total porosity and confiner capacity and increased air-filled porosity and bulk density relative to the sawdust control. Heiskanen (1999) investigated the hydrological properties of container media based on sphagnum peat and their potential implications for availability of water to seedlings after outplanting. He found that adding a coarse constituent (perlite) to peat increased air-filled porosity and saturated K of the medium, but decreased water retention (especially in wet conditions) and unsaturated K. Increasing the application rate of organic waste in the media resulted in a linear decrease in K_s ($p = 0.0001$) and τ ($p = 0.0001$), but an increase in D_s/D_0 ($p = 0.0003$). Significant (FBF vs CBF), (FBF vs CBF) × R. Lin and (FSS × CSS) × R. Lin interactions were observed for K_s. Another (FSS× CSS) × R. Lin significant interaction was observed for τ (Table 3). For K_s, the interaction (FBF vs CBF) for organic waste type (T) suggests that even though both FBF and CBF increased K_s (as showed by an F value of 9.25 and $p = 0.0001$), such an increase was higher in media amended with CBF as compared to FBF. The interactions (FBF vs CBF) × R. Lin and (FSS × CSS) × R. Lin for the rate of application suggest that K_s increased as the rate of application of waste increased. However, the increase was faster in the composted forms of bio-filter (CBF) and sewage sludge, this in comparison their respective fresh forms (FBF and FSS). The same explanation applies to the (FSS × CSS) × R. Lin significant interaction for τ. It can be concluded that composted forms of both bio-filter and sewage sludge were more likely to affect media physical properties (Ks and τ) than fresh forms. The effect of composted form of wastes on soil and media's physical properties have been studied by several authors. Carmona *et al*. (2003)

Table 3: Effect of organic waste type and rate of application the physical properties of growing media

Types	K_s (m sec^{-1})	f_a (m^3 m^{-3})	τ (m m^{-1})	D_s/D_o (m^2 sec^{-1} m^2 sec^{-1})
Organic waste type (T)				
FBF	0.062	0.268	2.36	0.0052
CBF	0.076	0.304	2.70	0.0050
FSS	0.066	0.268	2.35	0.0052
CSS	0.083	0.276	2.85	0.0044
FDP	0.068	0.274	2.28	0.0055
CDP	0.077	0.274	2.46	0.0051
Rate of application (R)				
10%	0.065	0.270	2.95	0.0042
20%	0.067	0.218	2.49	0.0040
30%	0.071	0.288	2.86	0.0046
40%	0.082	0.312	1.09	0.0131

Analysis of variance

		K_s		f_a		τ		D_s/D_o	
Types	df	F	Prob	F	Prob	F	Prob	F	Prob
Organic waste type (T)	5	9.25	0.0010	1.270	0.2830	0.72	0.6115	1.27	0.2360
(FBFvsCBF)		13.46	0.0004	0.010	0.9392	0.20	0.6567	2.68	0.0984
(FSSvsCSS)		0.88	0.3499	0.003	0.9821	0.43	0.5118	0.00	0.9592
(FDPvsCDP)		11.85	0.0009	0.330	0.5679	0.95	0.3319	1.41	0.2378
Rate of application (R)	3	30.35	0.0001	1.020	0.3854	3.98	0.0001	4.85	0.0035
R. Linear	1	85.76	0.0001	0.140	0.7088	7.85	0.0102	14.04	0.0003
R. Quadr.	1	3.13	0.0799	0.520	0.4729	2.60	0.1098	0.21	0.6514
Interaction	38								
(FBFvsCBF)×R. Lin		12.91	0.0005	0.250	0.6164	0.08	0.7835	3.21	0.0762
(FSSvsCSS) ×R. Lin		6.07	0.0155	1.480	0.2661	3.83	0.0504	3.31	0.0762
(FDPvsCDP)×R. Lin		1.22	0.5643	1.050	0.5455	1.45	0.2343	0.67	0.5987

studied the hydrological properties of fresh and composted cork container media. They found that when cork residues were composted for 7 months, important changes occurred in hydrological properties of the material as it became wetter. Water retention significantly increased from 45 to 54%, at a potential of 5 kPa, although this did not necessarily result in increased water available to plants. A study of the unsaturated hydraulic conductivity (K_{unsat}) of these materials revealed a significant decrease in the K_{unsat} water potential at 0-5 kPa, which corresponds to the range in which the irrigation with these substrates was usually carried out. The long composting process resulted in increased K_{unsat} between 4 and 5 times that of non-composted material, which would improve the water supply to the plant. Harry *et al*. (1999) reported that composted yard waste prepared from ground wood and grass clippings has the opposite effect to non-composted form. It improves plant growth, improves both drainage and water retention and can provide biological control of phytophthora root rot. The same results were obtained with composted tree barks. Olson *et al*. (2005) studied the effects of fresh versus composted manure on hydrological response from cropland. They hypothesized that composted manure would increase infiltration and decrease runoff compared to fresh manure because of its more uniform and finer particle size. Initially, they found that runoff rates and runoff coefficients were generally lower for the high and medium rates of fresh manure. However, they concluded that after 2 years of study, application of composted manure or fresh manure to cropland at rates up to 83 Mg ha^{-1} should have similar impacts on hydrologic response. The longer-term effects of fresh and composted forms of organic wastes should be examined to better understand potential hydrological and water quality differences.

Effects of Organic Wastes on the Growth of 3 Ornamentals Species

Except for *Calceolaria herbeorhybrida* which responded to both organic waste type ($p = 0.0001$) and their rate of application ($p = 0.0001$), both *Impatiens wallerana* ($p = 0.0004$) and *Tagetes patula* ($p = 0.0043$) plant dry weights were only significantly affected by the rate of application of organic wastes (Table 4).

Table 4: Effect of organic waste type and rate of application on Plant Dry Weight (mg) of *Tagete patula*, *Calceolaria herbeohybrida* and *Impatiens wallerana* after 4 months of container growth

Type	*Tagetes patula*	*Impatiens wallerana*	*Calceolaria herbeohybrida*
Organic waste type (T)			
FBF	239	323	394
CBF	225	256	223
FSS	235	335	252
CSS	202	256	327
FDP	237	246	283
CDP	296	323	345
Rate of application (R)			
10%	250	322	377
20%	277	321	312
30%	247	235	234
40%	184	237	238

Analysis of variance

		Tagetes patula		*Impatiens wallerana*		*Calceolaria herbeohybrida*	
Types of variation	df	F	Prob.	F	Prob.	F	Prob.
Organic waste Type (T)	5	1.990	0.0865	2.75	0.0570	6.68	0.0001
(FBFvsCBF)		0.220	0.6418	4.23	0.0240	5.76	0.0029
(FSSvsCSS)		1.080	0.3003	2.56	0.0460	5.71	0.0032
(FDPvsCDP)		3.600	0.0408	3.57	0.0320	6.22	0.0001
Rate of application (R)	3	4.680	0.0043	5.67	0.0004	10.76	0.0001
R.Linear		10.260	0.0018	12.12	0.0001	8.29	0.0001
R.Quadr.		3.080	0.0824	2.35	0.0870	1.78	0.1323
Interaction	38						
(FBFvsCBF)×R. Lin.		0.003	0.8513	3.05	0.0560	2.28	0.0690
(FSSvsCSS)×R. Lin.		0.430	0.5113	3.87	0.0390	1.96	0.1188
(FDPvsCDP)×R. Lin.		5.320	0.0007	8.54	0.0001	4.34	0.0043

Composted forms of sewage sludge, ($p = 0.0029$) and that of de-inked paper, ($p= 0.0001$) gave the highest plant dry weight for *Calceolara herbeorhybrida*, this as compared to fresh forms. The beneficial effects of composted forms of organic wastes on plant growth has been studied by other authors. In fact, it is generally suggested that composting an organic amendment or mulch before use stabilizes the material against wild nitrogen fluxes. Such finished composts do not perturb the nitrogen status of the soils and allow the crop to grow according to its nitrogen demands and resources without concern of nitrogen draft (Downer *et al*., 1997). Composted mulch with nitrogen produced the most flowers, while incorporation of fresh yard waste induced the most nitrogen draft. Compost stimulated more flowers than fresh materials, but nitrogen application was the most important factor for early flower development in petunia (Downer *et al*., 1997). Roe *et al*. (1994, 1997) studied the effect of composted sewage sludge on several vegetable crops. They found that pepper fruit and squash yields with composted sewage sludge were higher than those with other forms of wastes. Loeckea *et al*. (2004) studied corn growth response to composted and fresh solid swine manures. They found that corn treated with composted manure produced 12% greater aboveground dry mass (DM) in 2000 and 15% greater DM in 2001 than did corn treated with fresh manure. They concluded that composting swine hoop manure before field application appears to be an effective alternative to fresh-manure application for corn production. While composted forms of sewage sludge de-inked papers produced the highest plant growth, opposite results were observed for bio-filter waste where the fresh form gave the highest plant dry weight for *Calceolaria herbeohybrida*. The same trend was also apparent (even though not significant at 5% probability level) for *Tagetes patula* and *Impatiens wallerana* which seem to have their highest plant dry weight with the fresh forms of bio-filter and sewage sludge. Similar results were observed for field applications of composted poultry litter which resulted in 25% less corn biomass and grain yield than applications of raw poultry litter when these amendments were applied at the same total N rate (Cooperband *et al*., 2002). A substantial number of studies have demonstrated that animal manures, composts and compost extracts can increase or reduce plant growth beyond levels explainable by increases in nutrient supply (Loeckea *et al.*, 2004). Because of these potentially contradictory effects, the impacts of fresh and composted manures plant response performance cannot yet be predicted with confidence. Plant dry weight of *Tagetes patula* ($p = 0.0018$), *Impatiens wallerana* ($p = 0.0001$) and *Calceolara herbeorhybrida* ($p = 0.0001$) decreased linearly with increasing organic waste rate of application. Significant (FSS vs CSS) x R.Lin for *Impatiens wallerana* only and (FDP vs CDP) × R Lin interactions for all three ornamental species were observed (Table 3). They suggest that *Impatiens wallerana* grew well and decreased faster in media amended with FSS than CSS. Finally, all three species grew well and decreased faster in media amended with CDP than FDP.

Correlation between Plant Growth and the Physical Properties of Media

Correlation between plant growth and the physical properties of growing media are showed in Fig. 1 to 6. Air-filled porosity and saturated hydraulic conductivity did not significantly correlate with plant dry weight of any of the three species. However, the pore tortuosity factor significantly correlated with plant dry weight of *Impatiens wellerana* ($r = 0.87$), *Tagetes patula* ($r = 0.83$) and *Calceolaria herbeohybrida* ($r = 0.48$). As showed in Fig. 1-3, the best fit for the relationship between τ and PDW was obtained with a negative power trendline of the form PDW= $a\tau^b$, where a and b are coefficients. Each of these power trendlines clearly demonstrates that plant dry weight decreased as the pore tortuosity factor increased. The respective R^2 values are 0.23, 0.69 and 0.76 for *Calceolaria herbeohybrida*, *Tagetes patula* and *Impatiens wellarana*, respectively. However, the b coefficients of -0.79, -1,13 and -0.65 of the power trendline equations in Fig. 1, 2 and 3 are all nearly equal to -1.00.

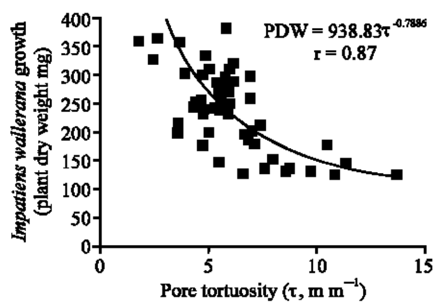

Fig. 1: Relationship between media pore tortuosity and growth (plant dry weight, mg) of *Impatiens wallerana*

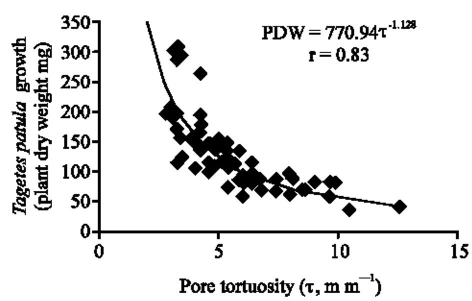

Fig. 2: Relationship between media pore tortuosity and growth (plant dry weight, mg) of *Tagetes patula*

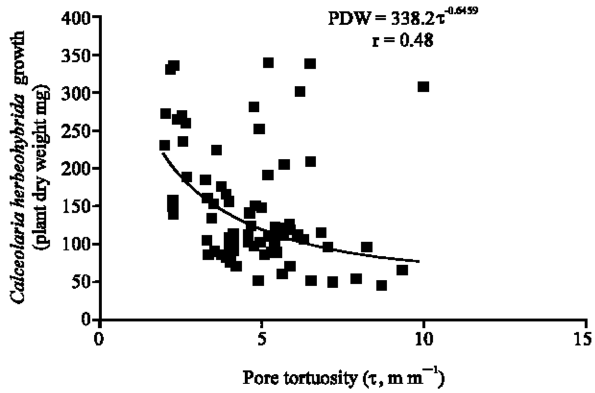

Fig. 3: Relationship between media pore tortuosity and growth (plant dry weight, mg) of *Calceolaria herbeohydrida*

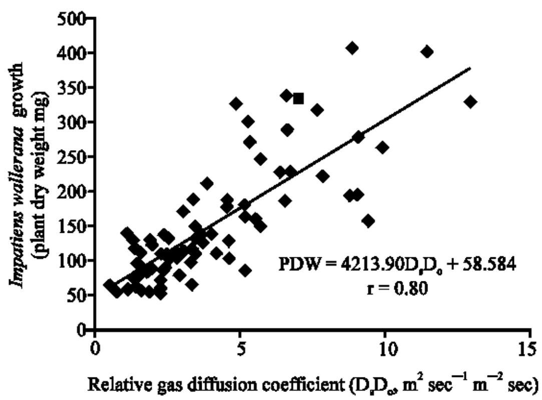

Fig. 4: Relationship between media gas diffusion coefficient and growth (plant dry weight, mg) of *Impatiens wallerana*

This suggests that the relationship between τ and PDW is still of linear nature. The best fit equations for the linear relationship between the relative gas diffusion coefficient and PDW are showed in Fig. 4, 5 and 6. DsDo linearly correlated with PDW of *Impatiens wallerana* ($p = 0.0001$, $r = 0.80$), *Tagetes patula* ($p = 0.0001$, $r = 0.71$) and *Calceolaria herbeohybrida* ($p = 0.0001$, $r = 0.67$). All the slopes were significant ($p<0.00001$) and positives, implying that PDW increased with increasing DsDo. Increase (slope) in PDW was a twice as much for *Impatiens wellarana* and *Tagetes patula* as compared *Calceolaria herbeohybrida*. The Best fit equations of Fig. 4, 5 and 6 also shows that PDW average rate (intercept) at the start period was negative for Tagetes patula, but positive for both *Calceolaria herbeohybrida* and *Impatiens wellarana*. However, a regression analysis revealed that all the intercepts were significant ($p<0.00001$) except for that of *Tagetes patula*. The lack of correlation between container plant growth and the storage properties of media (air-filled porosity) has been reported by several authors. In fact, many studies have reported no relationship (Brown and Emino, 1981; Karlovich and Fonteno, 1986; Ouimet *et al*., 1990) or minimal (De Rouin *et al*., 1988) relationships between air-filled porosity and plant growth. Caron *et al*. (2001) studied the growth of *Euphorbia pulcherima* in growing media containing large particle size. They found that root growth

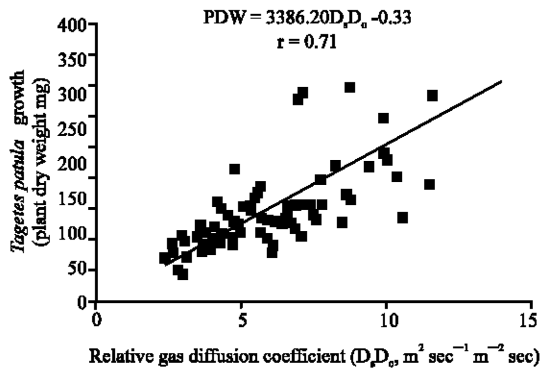

Fig. 5: Relationship between media gas diffusion coefficient and growth (plant dry weight, mg) of *Tagetes patula*

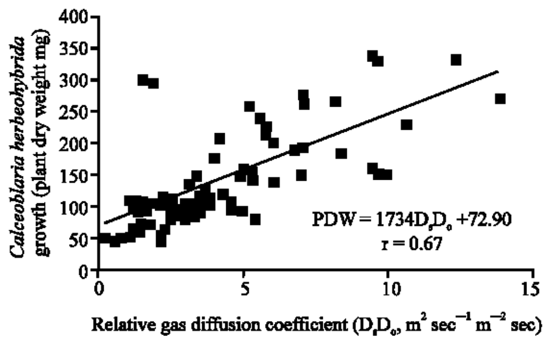

Fig. 6: Relationship between media gas diffusion coefficient and growth (plant dry weight, mg) of *Calceolaria herbeohybrida*

parameters were significantly and positively correlated to gas relative diffusivity but showed no correlation with air filled porosity. Bilderback and Lorscheider (1995) studied the physical properties of double-processed pine bark on rooting of *Photinia x fraseri* cuttings. They found that regression and correlation analyses indicated no relationship between percent volume of air space (air-filled porosity) or container capacity (water content) with rooting responses measured for any of the three species propagated. Wall and Heiskanen (2003) examined the effect of air-filled porosity and organic matter concentration of soil on growth of *Picea abies* seedlings after Transplanting. They found that the shoot height and mass growth as well as root mass were significantly higher in 20, 30 and 40% than in 5 and 10% air-filled porosity. Similarly, the existence of a correlation between plant growth and the exchange properties of media (pore tortuosity factor and gas diffusion coefficient) has been reported by Nkongolo and Caron (2006), Allaire *et al.* (1996) and Ball and Robertson (1994). Caron *et al.* (2001) studied the aeration in growing media containing large particle size and growth of *Euphorbia pulcherima*. They found that Root growth parameters were significantly and positively correlated to gas relative diffusivity but showed no correlation with air filled porosity. Caron and Nkongolo (1999) reported that in several studies in which the substrate physical properties were varied, air exchange properties (gas relative diffusivity) were more closely correlated to plant growth than was the air-filled porosity. τ and Ds/Do seem therefore to offer a promising tool for assessing the physical conditions of the root zone which relate to plant response in artificial mixes.

Significance to the Nursery Industry

Recent research results have shown that many urban and industrial by-products can successfully be used as inexpensive container growing media additives or substitutes for traditional organic ingredients such a peat. However, some of these products have also been reported to impair physical conditions of the media, thus reducing plant response. In addition, while media with adequate physical conditions are sought, measures of these properties related to plant response are also needed. As current assessments of the physical conditions of the root zone focuses on storage (Air-filled porosity and water holding capacity) characteristics which in many cases have hardly been related to plant response, there is therefore a need to investigate pore characteristics which regulate media storage and exchange properties. This investigation has found that organic waste type affected only K_s while their rate of application increased K_s and D_s/D_0 while decreasing τ. In light of the relationship between plant dry weight with D_s/D_0 and τ, it may useful to measure these parameters when assessing the suitability of media for plant growth.

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