Waste materials-based substrates for ornamental plant production: technical and environmental aspects

P. Arfaioli[1], L. Azzini[1], A. Cincinelli[2], M. Heřmánková[3], S. Lucchetti[4], C. Macci[5], G. Masciandaro[5], R. Scodellini[2], G. Renella[6], K. Waska[3] and F.P. Nicese[1,a]

[1]DAGRI, University of Florence, Piazzale delle Cascine 18, Florence, Italy; [2]Department of Chemistry "Ugo Schiff", University of Florence, Via della Lastruccia 3, Sesto Fiorentino (Florence), Italy; [3]EPS Biotechnology, V Pastouškách 205, Kunovice, Czech Republic; [4]Agri Vivai s.r.l, Via Casalina 118G, Pistoia, Italy; [5]CNR-ISE, Via Moruzzi 1, Pisa, Italy; [6]DAFNAE, University of Padua, Viale dell'Università 16, Legnaro (Padua), Italy.

Abstract

In the plant nursery sector, efforts have been made for some time to partially or totally replace peat-based substrates with growing media characterized by a lower environmental impact. In this perspective it was decided to evaluate a composted material obtained from dredged sediments and green waste, to be used as component for substrates in ornamental plant production, while evaluating the environmental implications of this operation. Fresh green waste consisting of corn cob, wood chips, grass and leaves were mixed in different rates (3:1, 1:1, 1:3 v/v) with dried dredged sediments taken from a small stream located in an urban area (Čejkovice, Czech Republic). These different mixtures were co-composted for six months, and the compost heaps were managed following standard compost protocols. To evaluate the progress of the co-composting process, the various mixtures were subjected to physical, chemical and biological analysis, during the entire period of co-composting. Eventually these mixes were taken to a plant nursery farm in Pistoia (Tuscany, Central Italy), and mixed in different ratios with classical nursery growing media (peat and pumice). Then, one-year-old vegetatively propagated plants of two typical evergreen shrubs (*Photinia* × *fraseri*, *Viburnum tinus*) were placed in 10-L (24 Ø cm) pots with differentiated substrates, added with 4.5 g L^{-1} of Basacote®. The growth of the plants tested is monitored (dry mass storage); at the same time, it was decided to use an LCA (life cycle assessment) analysis, to quantify the CO_2 emissions (kg CO_2 equivalent) deriving from the different phases (inputs, energy, transport, structures, etc.) of the production process, assessing the effect of these growing mixes on the environmental sustainability of plant nursery production.

Keywords: growing media, LCA, dredged sediments, green waste, co-composting

INTRODUCTION

The production of hardy ornamental nursery stocks is considered of great importance throughout Europe, and particularly in The Netherlands, Italy, Germany, France and Spain (EU Commission, 2019). Pistoia (43°54'N, 10°41'E; 30 m a.s.l.), near Florence, has a prominent role in ornamental plant production, since it is known as the greatest plant nursery district in Italy, with more than 4000 ha of field-grown plants and 1000 ha of container-grown plants (Lazzerini et al., 2016), which obviously require a great amount of potting mixes. Most of the substrates used in ornamental plant production for many years were peat-based (Ostos et al., 2008), but in recent years a constant cost increase of such input, together with environmental concerns due to peat mining (De Lucia et al., 2013), have convinced different authors to search for alternative materials to use in potting mixes. More in detail, various raw or composted waste by-products, as mushroom compost, paper mill sludge (Chong, 2005), almond shell waste (Urrestarazu et al., 2008), coir (or coconut fiber) (Mariotti et al., 2020) were tested as a total or partial alternative to peat moss in the growing media, with variable results in terms of plant quality production. Among these waste by-products, the use of dredged sediments

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[a]E-mail: francesco.nicese@unifi.it

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has been proposed as a low impact material, locally available, to replace peat as a substrate component (Mattei et al., 2017; Mattei et al., 2018). Obviously, these sediments need a remediation phase prior their reuse in growing mixes and in this perspective a soft remediation technology like phytoremediation can be sustainable and effective (Masciandaro et al., 2014). With this in view, green waste, made of pruned tree branch, hedge trimming, leaves, grass cuttings, and other green residues can represent an interesting, underutilized, waste category to use in a co-composting phase with the aim to improve sediment physico-chemical property for support plant growth (Mattei et al., 2016).

It was decided to evaluate a composted material obtained mixing dredged sediments and green waste, to be used as component in growing media for potted ornamental plant production. The progress of the co-composting process in the various growing mixes assembled was monitored through repeated physical, chemical, and biological analysis during the six months of co-composting.

Once the co-composting phase was accomplished, a cultivation phase was planned, with the aim to evaluate the effect of different substrates assembled with these waste materials on the growth of two ornamental container-grown species. Eventually, all the various step of this particular production chain were subjected to an environmental analysis using a LCA (life cycle assessment) approach.

MATERIALS AND METHODS

Co-composting phase

Fresh green waste consisting mainly of corn cob, wood chips, grass and leaves were mixed in different rates (3:1, 1:1, 1:3 v/v) with dried dredged sediments taken from a small stream located in an urban area (Čejkovice, Czech Republic). These different mixes were co-composted for six months, and the compost heaps were managed following standard compost protocols. The progress of the co-composting process in the different heaps was monitored through periodical physical, chemical, biochemical and toxicological assays, such as temperature, humidity, bulk density, organic matter, nutrients, microbial activity, phytotest, and pollutants.

Plant material and field experiment

In October 2020 one-year-old vegetatively propagated plants of two typical evergreen shrubs, Fraser Photinia (*Photinia × fraseri)* and Laurustinus (*Viburnum tinus*) were potted in 10-L (24 cm Ø) plastic containers with differentiated substrates, added with 4.5 g L^{-1} of Basacote® Plus (12M; 15N-15P_2O_5-15K_2O). Seven different substrates were assembled following the idea to find a good and sustainable growing media. Basically, it was decided to use the three co-composted mixes as they are or mixed with classic peat based substrates, a control treatment with peat moss and pumice was introduced as well (Table 1). A total of 280 plants (140 for each species) are now placed outdoor in a plant nursery in a randomized complete block design with 20 replicates per treatment. All the plants are equally spaced in a metal support grid, drip irrigated and the pots surface covered with natural coco coir fiber discs for weed control. Five plants per species were sampled to determine fresh weight of canopy and roots, as well as dry weight after the vegetative material was oven-dried (80°C) until constant weight. After five months from repotting, on March the 1st, four plants of each species per treatment were planted out, roots were washed free of media and the total height and fresh weight of the plants measured, as well as their dry weight, the shoot:root (S/R) and dry/fresh weight (DW/FW) ratio. This allowed us to evaluate the effect of the different substrates on the winter growth of the plants tested. All the data were subjected to analysis of variance using SPSS (Release 27.0). Treatment means were separated by LSD, with $p \leq 0.05$ level of significance.

Table 1. List of the different substrates used in the field experiment.

N°	Substrate (in volume)
1	Peatmoss – Pumice (1:1)
2	Peatmoss – Pumice (1:1) 50% – dredged sediments – green waste (3:1) 50%
3	Peatmoss – Pumice (1:1) 50% – dredged sediments – green waste (1:1) 50%
4	Peatmoss – Pumice (1:1) 50% – dredged sediments – green waste (1:3) 50%
5	Dredged sediments – green waste (3:1)
6	Dredged sediments – green waste (1:1)
7	Dredged sediments – green waste (1:3)

Life cycle assessment

The environmental analysis was carried out by calculating the emissions of greenhouse gases associated with the production of an ornamental plant in a 10-L pot (24 cm Ø), expressed in kilograms of CO_2 equivalent (kg CO_2 eq.), using a "gate to gate" approach and adhering to the regulations presented by the International Organization for Standardization within the normative 14044 (ISO, 2018). It was decided to limit the impact evaluation to the 24 cm Ø pots cultivation, leaving out the propagation and first cultivation phases. Within the system boundaries the emissions generated by the co-composting phase (collection and treatment of sediment and green waste, management and handling of the compost during the composting process) and by the cultivation phase (pots, irrigation, fertilizers, fuels and electricity used during cultivation) were included (Figure 1). All the emissions were calculated according to their Global Warming Potential considered over a period of 100 years (GWP100), a method adopted by both the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) for comparing the potential climate impact of emissions of different greenhouse gases (Shine et al., 2005).

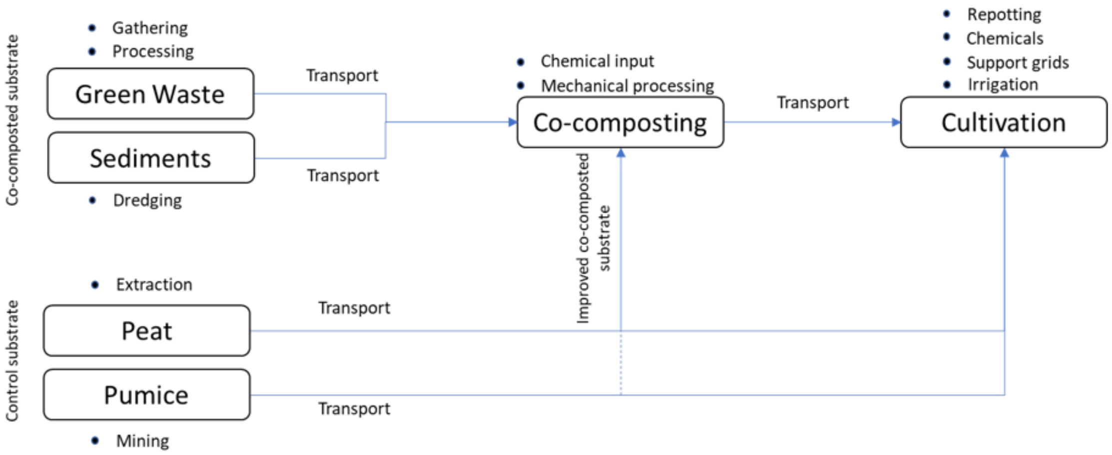

Figure 1. Flow chart of the plant nursery production process analyzed with LCA.

It was also decided not to consider the emissions generated by biogenic carbon. This because, as reported in previous works, when analyzing the life cycle of processes in which plant materials are involved, the impacts of the biogenic fraction of carbon are considered balanced with the carbon stored in the plants themselves during their growth (Guinée and Lindeijer, 2002; Frischknecht et al., 2004).

All data were analyzed using GaBi software (Sphera, http://www.gabi-software.com) in its version 10.0.1.92, using the proprietary database, updated to the version 2021.1.

RESULTS

Co-composting phase

Stable and mature products were obtained at the end of a six months co-composting process, as demonstrated by the decrease and stabilization of organic matter content, electrical conductivity, microbial activity and by the increase in humification rate in all the heaps (data not reported). Additionally, germination index approaching 100% and reduction of sediment organic contaminants (67, 32 and 27% in piles 3:1 1:1, and 1:3, respectively) were reached at the end of the composting phase. Consequently, these materials were used as they are or mixed to classic peat based substrates for the field experiment planned.

Substrate characteristics

The main characteristics of the seven substrates, reported in Table 2, were compared with Italian regulation for fertilizers (D.lgs. 75/2010).

Table 2. Main characteristics of the seven substrates tested.

	1	2	3	4	5	6	7	(*)
Bulk density (g cm^{-3})	0.3	0.5	0.6	0.3	0.7	0.8	1.0	<0.95
pH	4.8	7.0	7.0	6.4	6.9	7.6	7.5	4.5-8.5
EC[a] (dS m^{-1})	0.3	1.0	1.0	0.5	1.6	1.5	1.6	<1
TOC[b] (%)	13	3.7	7.7	10	2.4	4.5	6.6	>4
TN[c] (%)	0.4	0.3	0.5	0.5	0.3	0.4	0.7	<2.5
P_2O_5 (%)	0.012	0.004	0.005	0.010	0.001	0.001	0.005	<1.5
CEC[d] (meq 100 g^{-1})	42.6	26	38	45.5	28.8	44	45.7	

(*): D. lgs. 75/2010.

[a]EC: electrical conductivity.

[b]TOC: total organic carbon.

[c]TN: total nitrogen.

[d]CEC: cation exchange capacity.

The substrates revealed physical and chemical properties suitable for plant growth. The bulk density (BD) in all substrates had values below the Italian law limits for mixed growing media. The presence of peat reduced the BD of compost and in 3GW:1S + peat substrate reached values similar to control and optimal for growing media (<0.4 g cm^{-3}) (Abad et al., 2001), indicating a proper porosity for air circulation. In all substrates, pH ranged within the Italian law limits.

More in details, compost had relatively high values of pH compared to control, but adding peat to compost overcame this problem with a pH reduction, especially in 3GW:1S (substrate 4). The highest values for electrical conductivity (EC), detected in compost, were also reduced by adding peat, particularly to 3GW:1S, reaching values allowed for the Italian law. The total organic carbon (TOC) in tested substrates had values lower than control but higher than the law limit, except for 1GW:3S, 1GW:3S + peat, due to the presence of an high quantity of sediment (Mattei et al., 2016). On the other hand, the 3GW:1S + peat substrate showed values for TOC comparable to control one. Mixing compost (3GW:1S) and peat increased the total nitrogen (TN) compared to control, conferring to compost a role as nutrient source for plants (Raviv, 2005). The percentage of TN and phosphorous were much lower than the law thresholds, allowing to specifically use the fertilizers, related to the specific needs and the phenological phase of the plants. In addition, the results concerning the cation exchange capacity (CEC) suggested an efficient nutrient retention as well as a reduction of the nutrient leaching due to irrigation (Savvas and Gruda, 2018), especially in 3GW:1S and 3GW:1S + peat substrates, reaching values similar to control. However, the increased proportion of sediment in compost reduced CEC, even in presence of peat.

Plant growth

In this first period of growth, from October to February, both Laurustinus (Table 3) and Fraser Photinia (Table 4) showed a dry matter increase, regardless of the substrate tested. All the growth parameters, anyway, showed no statistical differences: both the plants grown in substrates with peat and co-composted matrix and the plants grown with fully waste materials-based substrates had similar height, dry matter increase and partitioning to the plants potted in control peat-based mixes. The S/R and DW/FW ratios showed the same trend in all the treatments, thus confirming a general balance among the plants tested.

Table 3. Height (cm), fresh and dry weight (g), shoot/root and dry/fresh weight ratio in Laurustinus plants after 5 months of cultivation (initial DW: 110 g).

Substrate	H[a]	FW[b]	DW[c]			S/R[d]	DW/FW
			Shoots	Roots	Total		
1	73.5 ns	610.3 ns	130.1 ns	40.2 ns	170.3 ns	3.2 ns	0.28 ns
2	63.8	445.3	107.3	32.7	140.0	3.3	0.31
3	60.5	453.6	106.0	35.7	141.7	3.0	0.31
4	62.5	565.5	131.5	41.0	172.5	3.2	0.31
5	70.8	424.2	105.5	31.0	136.5	3.4	0.32
6	67.0	434.3	108.2	32.1	140.3	3.4	0.32
7	72.5	702.1	143.6	53.6	197.2	2.7	0.28

[a] H: height.

[b] FW: fresh weight.

[c] DW: dry weight.

[d] S/R: shoot/root ratio.

Table 4. Height (cm), fresh and dry weight (g), shoot/root and dry/fresh weight ratio in Fraser Photinia plants after 5 months of cultivation (initial DW: 86 g).

Substrate	H[a]	FW[b]	DW[c]			S/R[d]	DW/FW
			Shoots	Roots	Total		
1	60.8 ns	396.3 ns	79.6 ns	35.4 ns	115.0 ns	2.2 ns	0.29 ns
2	61.5	367.1	82.7	33.4	116.1	2.5	0.32
3	59.5	318.2	74.4	26.4	100.8	2.8	0.32
4	60.3	339.5	76.2	29.5	105.7	2.6	0.31
5	61.7	381.1	83.5	47.7	131.2	1.8	0.34
6	69.5	364.4	85.2	36.0	121.2	2.4	0.33
7	54.5	279.9	63.8	26.8	90.6	2.4	0.32

[a] H: height.

[b] FW: fresh weight.

[c] DW: dry weight.

[d] S/R: shoot/root ratio.

Life cycle assessment

The results of the life cycle analysis carried out are shown in Table 5. Analyzing the results for the various phases considered, it is possible to see how the cultivation phase, identical for all the seven treatments (no changes in cultivation inputs other than substrate), generates an emission of 0.82 kg CO_2 eq. plant^{-1}, with a percentage of the total impact shifting between a minimum of 59% up to a maximum of over 91% depending on the thesis considered. These emissions must be added with those generated by the substrates production, where the more impactful turns out to be the control growing media consisting of peat and pumice (0.57 kg CO_2 eq.). After the control mix, the three substrates obtained by combining the co-composted material with the peat-pumice growing media showed the highest emissions, while the three co-compost based mixes were the less impactful, with the lowest emissions per plant produced, only 0.08-0.12 kg CO_2 eq., corresponding to 8.9-12.8% of the total impact.

Table 5. Emissions due to peat-based and co-compost fraction and to cultivation inputs. Total values (kg CO_2 eq. plant^{-1}) and percentage distribution (%).

Substrate	Peat/Pumice		Co-compost		Cultivation		Total
	kg	%	kg	%	kg	%	kg
1	0.57	41.0			0.82	59.0	1.39
2	0.34	28.6	0.03	2.5	0.82	68.9	1.19
3	0.34	28.8	0.02	1.7	0.82	69.5	1.18
4	0.34	28.3	0.04	3.3	0.82	68.3	1.20
5			0.10	10.9	0.82	89.1	0.92
6			0.08	8.9	0.82	91.1	0.90
7			0.12	12.8	0.82	87.2	0.94

DISCUSSION

The results of the analysis carried out on the co-composting phase clearly showed the effectiveness of this process to transform dredged sediments and green wastes into substrates to introduce as an alternative to classic growing media for plant nurseries. Among the physical and chemical properties taken into account, pH was one of the most critical parameters, with relatively high values compared to control, beyond neutrality in a couple of cases (substrate 5 and 6); this could be a problem using these mixes with sensitive plants (Raviv. 2013), though with substrates 2-3-4 (50% of peat/pumice mix added to waste materials) we had an improvement, with pH ranging from 6.4 to 7. Another critical point was the electrical conductivity (EC), which was over the limits of the Italian law (D. lgs. 75/2010) in all the growing mixes done with 100% of co-composted materials. Adding peat (substrates 2-3-4) had a beneficial effect on EC, whose values resulted under the Italian regulation. However, in all substrates the EC was below 2 dS m^{-1}, thus negligible effects for crop plants are expected (Miller and Curtin, 2007). It is of great importance to point out the low levels of TN and phosphorous in the co-composted mixes, thus allowing the use of specific fertilizers; in fact, besides proper chemical and physical properties, one of the most important aspect in growing media selection is the need to meet the requirements of growers (Barrett et al., 2016).

The results on plant growth must be considered as very preliminary, mainly because they are related to the first five months of the experiment, from October to February. All the plants showed a certain winter growth, with an increase in dry matter of about 25% (Fraser Photinia), up to 45% (Laurustinus). This is quite obvious considering that the two species are evergreen shrubs thus showing a limited winter rest period. Obviously, this short period of growth didn't allow the effect of different substrates to show as it was expected; probably with the start of the growing season, in April, the various treatments will show more relevant differences.

The LCA analysis has clearly demonstrated the importance of the classic peat-based substrates as CO_2 emission factors in the production process, with 40% of the total emissions. At the same time, the potential of these waste materials to limit the emissions of this production was demonstrated, with average reduction in kg CO_2 eq. ranging from 15% with a partial substitution of peat (substrates 2-3-4) to 35% using co-composted substrates as they are (substrates 5-6-7).

This first period of the experiment has highlighted the prospect of using waste materials such as dredged sediments and green wastes to assemble plant nursery growing media, with a significant increase of the environmental sustainability of this production process. However, a final assessment of the suitability of these waste materials to replace, partially or totally, peat moss substrates will be possible after the forthcoming growing season, with the evaluation of the summer growth of the plants tested.

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