Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media

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Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media

The quality of compost and its suitability for agricultural application depend upon physical and chemical parameters such as water-holding capacity, porosity, pH, electrical conductivity, C/N ratio, available nutrients and the absence of toxic substances. In the present study a complete characterization of an industrial municipal solid waste compost (MSWC) based on standardized European methods (CEN) for soil improvers and growing media was obtained, and compared with the quality of other Spanish composted biowaste and conventional substrates such as peat and pine bark. The MSWC was obtained from the main composting plant in Galicia (Spain), which processes organic waste that has been separated at origin and collected from more than 100 000 inhabitants. The MSWC presented a lower C/N ratio (15) than peat (84) and composted pine bark (CPB) (211), but had a similar ratio to other marketed MSWC. The nutrients and heavy metals were extracted using different recommended solvents (water, $CaCl_2$ + diethylen triamin pentaacetic acid, and *aqua regia*). The nutrient concentrations of composted urban waste or manure were much higher than those of peat, CPB or pine bark. On the basis of the results of the plant tolerance test, the MSWC could be employed directly as a soil improver, but would need to be diluted with other low-salt components such as peat or CPB before being used as a growing media.

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Introduction

Organic waste composting is a controlled bioprocess that has been proposed as an alternative to landfilling and the incineration of municipal solid waste (MSW) (Rosen *et al.* 1993, Ribeiro *et al.* 2000, Soumare *et al.* 2003, Manios 2004, Adani *et al.* 2004). Composting is usually carried out by aerobic processes, although more recently an anaerobic pre-treatment of MSW has also being utilized, followed by an aerobic curing step (Vogt *et al.* 2002, Silva *et al.* 2004). During composting, several groups of bacteria, yeasts and fungi metabolize the waste to produce a stable organic-rich, soil-like material, while producing CO_2, energy and microbial biomass (de Bertoldi *et al.* 1983). Aerobic MSW composting facilities include a pre-processing step, consisting of an initial screening to remove contaminants and recyclable materials, even if the organic waste has already been separated at its origin. The organic solid waste then remains in windrows, static piles, aerated piles or in composting tunnels for several weeks. During this period in which active decomposition of organic waste takes place, the composting material is aerated periodically, either by mechanical turning or by means of forced aeration through open floor systems. After the active composting period the partially decomposed biowaste requires additional curing for at least 2 or 3 months in order to produce mature and stable compost, which can be used in agriculture, soil reclamation, landscaping and gardening, and as a component of growing media for containerized plants.

Composting facilities that process municipally generated feedstocks are designed and operated primarily to divert materials from landfills and other forms of disposal (Glenn 1999). Nevertheless, compost quality not only defines the marketing potential of the product and in most cases, the viability of the treatment plant, but also the long-term acceptability of biological treatment as a valuable option in the waste-disposal hierarchy (Lasaridi *et al.* 2006). Therefore, it is crucial for compost producers to change their main objectives from landfill diversion to product manufacturing (Goldstein 2001). For this, separation of organic waste at origin has to be improved, and the composting facilities have to be operated with the aim of producing high quality compost with potential value-added markets.

The use of the composted organic fraction of urban residues as soil amendment may be a method of improving the low organic matter (OM) content of many cultivated soils in many countries, particularly in the Mediterranean area, where soil OM has gradually decreased over recent years and chronic deficiency of soil OM is occurring. Furthermore, low-cost composted urban waste materials are increasingly being evaluated as substitutes for non-renewable resources such as peat in the creation of growing media (Ribeiro *et al.* 2000, Fernández 2004). Compost that is intended for use as a growing media should meet more stringent quality criteria in comparison with compost used in reclamation of marginal and degraded soils or as landfill cover. The most important characteristics of MSW composts that may affect their use as growing media derive from their physical properties (air and water supply), from their chemical properties (pH, electrical conductivity and nutrient content) and from the absence of toxic components, including heavy metals, organic compounds and pathogens. Consequently, an exhaustive analysis of the substrate is necessary before the compost can become a commercially viable product. The European Committee for Standardization has been working to harmonize standards for soil improvers and growing media throughout the European Union (EU) and standard analytical methods were launched from 1999 to 2001 and these were adapted by translation to the Spanish standards from 2000 to 2002.

In the present study, a MSW compost produced on an industrial scale in Galicia (north-west Spain) from urban organic waste separated at origin was characterized by employing the standardized European methods (CEN) for soil amendments and growing media, and compared with marketed Spanish MSW composts and locally produced composted biowastes, as well as with peat and pine bark, which are commonly used as components of potting mixes. The evaluation of compost as a growing media was selected because of the high demand for plant substrates in Spain, and particularly in the region of Galicia, due to the relevance of ornamental plant and cut flower production in the country, and the increasing limitations on conventional peat-based substrates. Moreover, the assessment of compost quality and the prospect of potential value-added markets would not only help to improve the social acceptance of this product, and to eliminate the barriers to market development that often exist because of a lack of knowledge, but also to promote composting as the preferential treatment system for organic waste materials.

Materials and methods

MSW compost from Galicia

MSW compost (MSWC) was obtained from one of the two main composting facilities in Galicia (Spain). This plant has been operating since 2003 and processes the organic waste collected from more than 100 000 inhabitants. In spite of the fact that specific containers were made available for collecting only biodegradable materials, in 2005 this organic fraction contained 28% of non-biodegradable materials at the beginning of the process. Figure 1 shows the schema of the procedure followed to obtain the MSWC which was used in this study. First, the source-segregated organic fraction of MSW is sieved through a trommel (only fractions of the composting feedstock with a maximum dimension of less than 70 mm will go to the digestion chamber). Then the MSW is mixed with green waste to facilitate the aeration during aerobic composting. The biowaste remains in the digestion tunnel for 15 days, and during this period the temperature, aeration and moisture are periodically controlled. Then, composting continues in windrows for 4–5 months. Periodically, the MSWC is turned and aerated to obtain a mature and stable product. Finally, the inert material is removed from the mature compost by means of a trommel and a stoner. The MSWC investigated in the present study is not being marketed at present, although it has been employed as soil amendment in experimental trials in vineyards and used by the local authorities for landfill sealing.

Comparative composts

Other Spanish composts were included in the characterization programme in order to compare the MSWC proper-

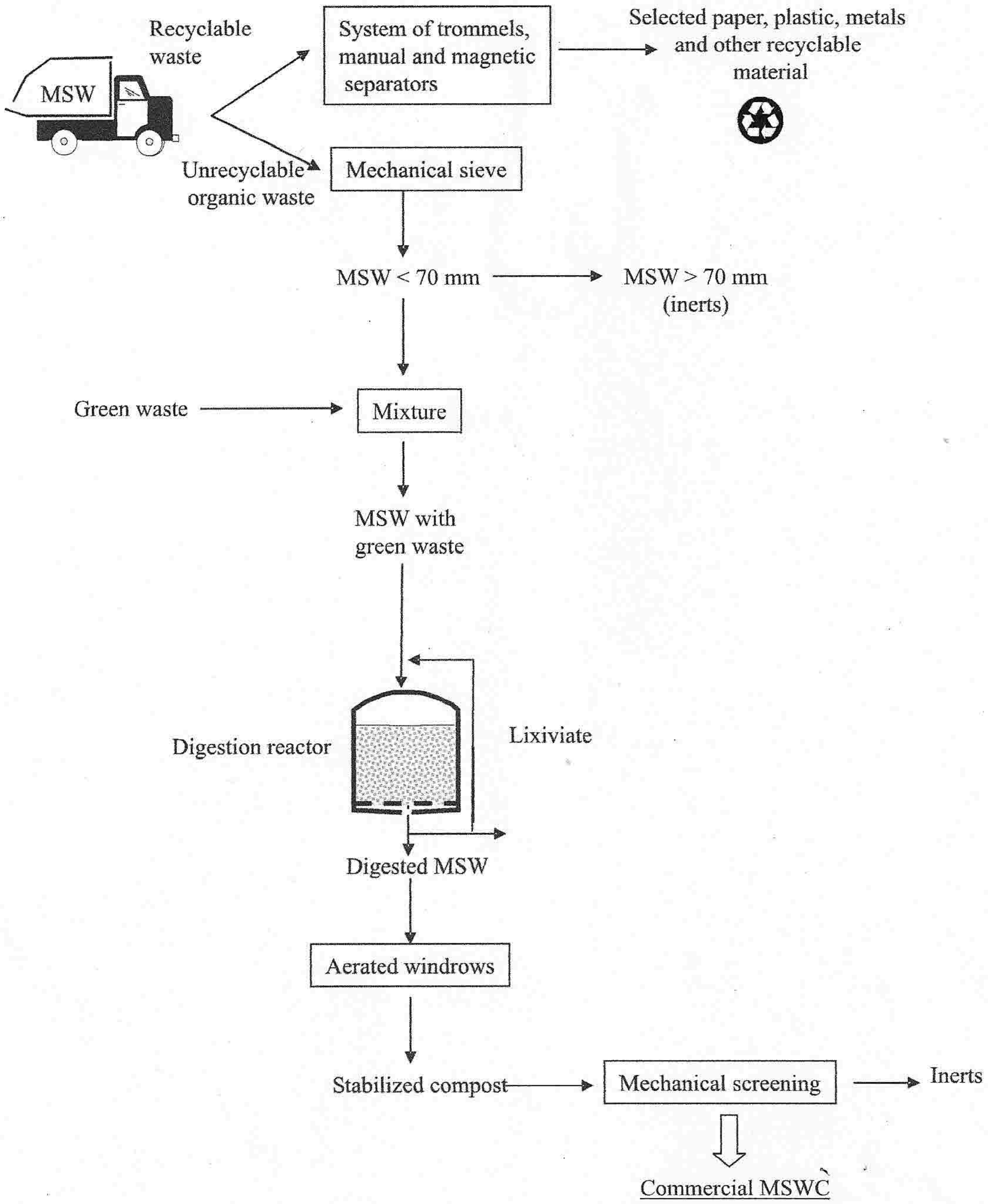

Fig. 1: Scheme of the process followed to obtain the municipal solid waste compost (MSWC) on an industrial scale in Galicia (Spain).

ties with those of marketed compost from high-standard MSW treatment facilities, as well as with other composted biowastes that are available locally and could compete with MSWC for use as soil amendment or growing media for plants. Table 1 summarizes all the materials analysed in this study and the nomenclature employed to designate them. Commercial compost obtained from MSW mixed with green waste (MSGW) and commercial compost mostly from municipal garden pruning and trimmings mixed with sewage sludge (MGSS) were supplied by one of the main compost producers in Cataluña (Spain). The other two composted materials were produced in the region: mixed manure vermicompost (MV) came from Ourense and composted pine bark (CPB) came from Lugo. Moreover, non-composted, sterilized pine bark (PB) marketed by Dermont (A Coruña) and *Sphagnum*

Table 1: Nomenclature of the substrates evaluated in this work.

Substrate	Nomenclature
MSW compost	MSWC
Composted green waste and MSW	MSGW
Composted green waste and sewage sludge	MGSS
Vermicompost from manure	MV
Composted pine bark	CPB
Pine bark	PB
Peat	Peat

peat (peat) supplied by Miksskaar AS (Estonia) were also studied, because these types of materials are commonly used in potting mixes.

Physicochemical characterization

The physicochemical parameters of the composts were determined by following the Spanish version (AENOR 2000, 2001, 2002) of European methods for soil amendment and substrate characterization, elaborated by CEN/Technical Commission 223 (UNE-EN 13037, 13038, 13040, 13041, 13049, 13650, 13651, 13652 and 13654–1). For all analyses, fresh materials were sieved to < 20 mm and homogenized. Moisture was determined by drying at 105°C until constant weight. Electrical conductivity (EC) and pH were determined in aqueous extracts of fresh samples (substrate/extractant ratio: 1/5, v/v). Inorganic nitrogen (NO_3^--N and NH_4^+-N) was determined by extraction with distilled water or $CaCl_2$ + DTPA and steam distillation. The available P was extracted with water or $CaCl_2$ + diethylen triamin pentaacetic acid (DTPA) and measured by UV-VIS spectrophotometry of the phosphomolibdic complex at 840 nm. The amounts of K and Mg available were evaluated after extraction with distilled water or $CaCl_2$ + DTPA and measured by flame spectrophotometry. OM was determined, in ground samples dried at 105°C, by weight loss after combustion at 450°C for 6 h, and total nitrogen (N) was evaluated by Kjeldahl digestion and steam distillation. Dissolved organic carbon (C_w) was determined by the wet dichromate oxidation method on 1 : 10 compost : water extracts (Zmora-Nahum *et al.* 2005). The total P, K, Ca and heavy metals (HM) were extracted with HCl and HNO_3 (3 : 1 ratio); the concentrations of K, Ca and HM were measured by atomic absorption spectrophotometry and that of P by UV-VIS spectrophotometry. Physical parameters in substrates (compacted bulk density, dry bulk density, air volume and water capacity at –10 cm, and total air space) were obtained by following the UNE-EN 13040 and 13041 UNE-EN methods (AENOR 2001). The analyses were carried out in triplicate, and the corresponding results are reported as mean values.

Plant tolerance study

To test the plant tolerance of the composted substrates, a biological test was carried out in triplicate, with spring barley seeds (*Hordeum vulgare* L.). The procedure was based on the method proposed by the German Federal Quality Assurance Organization, (FCQAO 1994). As the standard soil proposed by the FCQAO as reference substrate was not available in Spain, a general purpose commercial substrate, consisting of peat and perlite (EEO), which was similar to that employed in the Australian standards (1996), was used instead. Pots, 12 cm in diameter and 7 cm high, were loosely filled with standard substrate mixed with 25 or 50% of the tested materials, and watered. After a short period to allow the surplus water to drain away, 50 seeds of *H. vulgare* were sown and the pots were covered with a glass plate to reduce evaporative water losses. A multinutrient solution (Welgro Standard Plus® commercial; Química Masso S.A., Barcelona, Spain) containing 17% N, 30% P, 15% K, 0.13% Fe, 0.052% Mn, 0.06% Zn, 0.02% B and 0.005% Mo was added to the substrates in order to obtain 220 mg N L^{-1} substrate, 388 mg P L^{-1} and 194 mg K L^{-1}. The planted pots were kept in the greenhouse for 10 days at a temperature of 20°C with a light strength of 2150 lux and a 12 h photoperiod. The glass plates were removed when the germinated plants touched them. At the end of the growth period the plants were harvested by cuting them off exactly between the root and stalk and the fresh shoot mass was recorded. The yields were expressed as a percentage in relation to the mean yield of the standard substrate using equation (1) (FCQAO, 1994).

$$FM(r)_{25\ \text{or}\ 50\%} = (FM_{25\ \text{or}\ 50\%}/FM_{EE0}) \times 100 \tag{1}$$

where $FM(r)_{25\ \text{or}\ 50\%}$ is the relative yield of the tested materials with respect to the comparison substrate EE0 (%); $FM_{25\ \text{or}\ 50\%}$ is the mean fresh mass yield of the tested materials (g) and FM_{EE0} is the mean fresh mass yield of the comparison substrate (g).

Statistical analysis

Data were subjected to an analysis of variance by using the SPSS statistical software package and significant treatment differences were separated by Turkey's multiple range test at $P < 0.05$.

Results and discussion

Chemical analysis

The results of the chemical analyses are shown in Table 2. The composts obtained from organic municipal solid waste (MSWC and MSGW) presented the highest pH values, whereas uncomposted lignocellulosic materials (PB and peat) showed the lowest pH (Table 2). According to Abad *et al.* (2001) an acceptable EC value, obtained after 1 : 6 (v : v) water extractions of substrates, should be lower than 0.5 dS m^{-1}. Other authors (Noguera *et al.* 2003) have proposed an acceptable range of values for EC of between 0.75 and 1.99 dS m^{-1}; however this range is only valid when EC has been determined in extract from saturated media. So, taking into account the limits proposed by Abad *et al.* (2001), the EC values for MSWC, MSGW and MGSS were not acceptable whereas the EC values obtained for PB and peat were less than 0.4 dS m^{-1}.

Table 2: General chemical parameters of aerobic MSW compost compared with other potential substrate components. All analysis were determined in fresh substrates except C, OM, C_w and N.[1]

	Units	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
M	%	42.8a	30.6a	53.0a	46.2a	65.4a	45.4a	50.2a
I	%	5.0	0.5	1.6	ND	ND	ND	ND
CBD	g L^{-1}	531	533	474	593	78	181	154
pH		8.2f	9.2g	7.3d	7.9e	6.2c	5.5b	3.9a
EC	dS m^{-1}	2.4d	1.2c	1.4c	0.7b	0.4b	0.4×10^{-1}a	0.2×10^{-2}a
OM	%	39.7a b	42.9b	51.5c	37.6a	98.1d	96.8d	98.8d
C	%	23.0a b	24.8b	29.8c	21.7a	57.0d	56.2d	57.0d
C_w	mg kg^{-1}	5.71b	7.75c	5.12b	3.13c	5.10b	–	–
N	%	1.5d	1.7e	1.8e	1.0c	0.3a	0.2a	0.7b
C/N		15a	14a	15a	21a	211c	230d	84b
C_w/N		0.39ab	0.46b	0.28a	0.31a	1.70c	–	–

M, moisture; I, inert material; CBD, compacted bulk density; EC, electrical conductivity; OM, organic matter; C, carbon; N, nitrogen; C/N, carbon/nitrogen ratio; C_w/N, water soluble carbon/total nitrogen ratio; ND, not detected; –, not determined. For definitions of other abbreviations see Table 1.

[1]Values are the means of three determinations and different letters in each row indicate significant differences as determined by the Tukey test at $P < 0.05$.

The OM contents were higher in peat, PB or CPB (> 96%) in comparison with the other composted materials (< 53%). In particular, the OM values of MSW composts were well below the 80% OM proposed by Noguera *et al.* (2003) as an optimum value for substrates, but exceeded the minimum content of 35% OM required by Spanish legislation for compost.

The concentration of N in the compost feedstocks is one of the most important factors for the success of the composting process. Most of the N in composting mixtures is organic, principally as part of the structure of proteins and a small part of this organic N is mineralized to ammonia and nitrate by ammonification and nitrification reactions. In the present study the N contents were statistically higher in the MSW composts than in peat, PB or CPB. The C/N ratio decreases during composting, and can be used as a measure of the stability of the compost (Sánchez-Monedero *et al.* 2004), although the final ratios depend up on the characteristics of the feedstocks. Usually, compost can be considered stable when the C/N ratio is approximately 17 or less, unless lignocellulosic material remains. In the present study the MSW composts and MV showed C/N ratios 15–16, which were indicative of stable compost. Nevertheless, those corresponding to P, CPB and PB were very high (C/N > 84), which was probably due to the high content of lignocellulosic materials that show a very slow mineralization. The ratio of soluble C/nitrogen (C_w/N) is considered a better indicator of compost stability than C/N (Hue & Liu 1995, Bernal *et al.* 1998). The stability of the MSW composts and MV was confirmed by C_w/N ratios that were less than the value of 0.70 proposed by Hue and Liu (1995) as an index of compost maturity, and even under the most stringent limit, $C_w/N < 0.55$, proposed by Bernal *et al.* (1998).

Various recommended standard procedures have been proposed for the evaluation of nutrients in composted substrates. In the methods proposed by the US Composting Council (1997), nutrient analysis is conducted on nitric acid extracts, whereas compost analyses based on the Australian Standards (1996) use distilled or deionized water. In the German standard methods for compost analysis (FCQAO 1994), soluble NO_3^--N, NH_4^+-N and Mg are analysed in $CaCl_2$ + DTPA, and P and K in a solution of calcium acetate, calcium lactate and acetic acid (CAL method). In order to compare the efficiency of the various extractants and to allow for comparison with other analyses found in the literature, water or $CaCl_2$ + DTPA were used in the present study to extract the available nutrients and heavy metals (HM), whereas HCl + HNO_3 (*aqua regia*) was used to determine the total concentrations, following the Spanish version (AENOR 2000, 2001, 2002) of the CEN TC 223 standards.

In composts based on MSW, water extracted more NO_3^--N and NH_4^+-N from the substrates than $CaCl_2$ + DTPA. An inter-laboratory test conducted at the request of CEN TC 223 also showed a higher solubility of NO_3^--N in water than in $CaCl_2$ + DTPA but a similar or slightly higher solubility of NH_4^+-N in $CaCl_2$ + DTPA (AENOR 2002; 13651, 13652). This fact could be related to differences in the pH of the extractants and Ca concentrations in the substrates. The highest NH_4^+-N concentrations were found in substrates obtained from lignocellulosic materials (MGSS, CPB and peat) and the lowest NH_4^+-N concentration was found in the manure vermicompost (MV). The extent of the nitrifica-

Table 3: Nutrients extracted with different agents.[1]

Nutrients extracted with water ($mg\ kg^{-1}$)							
	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
NH_4^+-N	18c	13b	59e	ND	24d	9a	36f
NO_3^--N	67b c	105c d	804e	130d	32a b	ND	47a b
P	47e	39d	22c	212f	4a	8b	3a
Mg	100c	49b	237d	230d	1a	5a	1a
K	1594f	1525e	843d	584c	37a	126b	16a
Ca	542d	302c	1240e	170b	8a	15a	9a
Nutrients extracted with Ca Cl_2 + DTPA ($mg\ kg^{-1}$)							
	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
NH_4^+-N	12b	3a	10a b	3a	40c	11b	163d
NO_3^--N	50c	52c	353e	157d	44c	1a	24b
P	387b	507c	604c	4087d	1a	6a	1a
Mg	876c	1154e	1086d	2406f	151a	268b	161a
K	3315c	6456d	2170b	1548b	255a	625a	41a
Nutrients extracted with HCl + HNO_3 ($mg\ kg^{-1}$)							
	MSWC	MSGW	MGSS	H	CPB	PB	Peat
P	10276d	3367b	8945c	19210e	147a	173a	206a
K	4076b	8243c	4846b	3437b	888a	1355a	199a
Ca	80412b	84338b	87377b	69802b	2499a	1951a	1644a

ND, not detected. For definition of other abbreviations see Table 1.
[1]Values are the means of three determinations and different letters in each row indicate significant differences as determined by the Tukey test at $P < 0.05$.

tion process has been used as a maturity index for composting (Sánchez-Monedero *et al.* 2004). For all the studied materials, the concentration of NO_3^--N was higher than the concentration of NH_4^+-N, thus confirming the maturity of the compost. The NO_3^--N content of MSWC was higher than the concentration obtained in CPB, PB, and statistically equal to that of MSGW, either in water or in $CaCl_2$ + DTPA (Table 3).

Table 3 also shows the concentrations of P, Mg, K and Ca solubilized in water, P, Mg and K solubilized with $CaCl_2$ + DTPA and P, K and Ca solubilized with HNO_3 + HCl (*aqua regia*). Although nutrient concentrations in growing media are generally reported in $mg\ L^{-1}$ substrate, for consistency throughout the text the concentrations are indicated in $mg\ kg^{-1}$, as heavy metal limits are usually reported in these units. The nutrient concentrations in $mg\ L^{-1}$ can be obtained from concentrations in $mg\ kg^{-1}$ by multiplying this value by the compacted bulk density (CBD) values (in $kg\ L^{-1}$) included in Table 2. The first two extractants aim to solubilize the nutrients that are immediately available for plants, whereas the extraction of nutrients in *aqua regia* gives an idea of the total amount of nutrients that can be made available during the mineralization of substrates. From the data shown in Table 3 it can be deduced that MV would be an important supplier of available and total P, but MSWC and MSGW (both obtained from organic urban refuse) also contain high available nutrient concentrations, mainly K, Mg and Ca. On the contrary, CPB, PB and peat showed very low concentrations of available nutrients, mostly in water, so therefore they would be almost ineffective as nutrients suppliers. Consequently, it appears that less fertilization would be needed when MSWC was used as soil amendment or substrate for plants, whereas fertilization would be needed when CPB, PB, and peat were used as substrates.

The availability of nutrients depended on the type of compost and the element considered. Thus, for MSWC, the concentrations of P and Mg extracted in $CaCl_2$ + DTPA were eight times higher than using water, whereas the K extracted in $CaCl_2$ + DTPA was twice that extracted in water. Statistically, CPB and peat supplied the same concentrations of available and total nutrients, whereas MSWC, MGSS and MV presented the same concentrations of total K and Ca.

Despite the potential benefits of using compost as soil amendment or substrate component, the application of compost contaminated with toxic metals will be very harmful to the environment (Ciba *et al.* 2003). Some of the HM in the compost are plant micronutrients, such as Fe, Mn, Zn, Cu,

Table 4: Heavy metals extracted with different solutions.[1]

Heavy metals extracted with water (mg kg^{-1})							
	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
Fe	96.8c	63.5b	10.6a	12.6a	2.4a	5.0a	3.7a
Mn	1.8c	1.2b	0.40a	0.6a	ND	ND	ND
Cu	13.4b	0.7a	0.2a	0.4a	ND	ND	ND
Zn	9.6c	1.4b	0.50a	1.1b	ND	0.3	ND
Cd	ND	ND	ND	ND	ND	ND	ND
Pb	8.9b	3.8a	3.9a	3.3a	ND	ND	ND
Cr	0.4a	0.1a	ND	ND	ND	ND	ND
Ni	1.7	ND	ND	ND	ND	ND	ND
Heavy metals extracted with $CaCl_2$ + DTPA (mg kg^{-1})							
	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
Fe	864f	309d	210c	942g	31a	625e	69b
Mn	70d	56c	48b	142e	11a	6a	8a
Cu	153.0c	3.3a	6.1a	32.4b	2.5a	0.7a	0.9a
Zn	267e	41c	50c	228d	29b	6a	5a
Cd	0.4a	0.2a	0.2a	0.2a	0.6a	0.1a	0.1a
Pb	92c	34b	34b	17a	6a	4a	9a
Cr	0.7a	0.4a	0.5a	0.8a	0.4a	0.2a	0.2a
Ni	5.1c	0.7a	0.8a	1.7a b	2.6b	1.1a	1.9b
Heavy metals extracted with HCl + HNO_3 (mg kg^{-1})							
	MSWC	MSGW	MGSS	MV	CPB	PB	Peat
Fe	24418d	14368b	24428d	18635c	1047a	1289a	385a
Mn	455b c	322b	406b	624c	75a	96a	16a
Cu	829f	52c	688e	144d	4a	17b	1a
Zn	1149g	200d	896f	689e	70c	33b	8a
Cd	3.1c	2.1b	2.7b c	2.0b	2.3b c	0.9a	0.1a
Pb	223e	62c	180d	33b	14a b	4a	2a
Cr	77d	17b c	68d	23c	7a b	4a b	1a
Ni	75d	25c	71d	27c	12b	17b	1a
Hg	0.58c	0.51c	0.21b	0.03a	0.11b	0.20b	0.23b

ND, not detected. For definition of abbreviations see Table 1.
[1]Values are the means of three determinations and different letters in each row indicate significant differences as determined by the Tukey test at $P < 0.05$.

Ni, and therefore, the addition of these elements with compost could be favourable whenever excessive, phytotoxic levels, are not reached. Other elements such as Pb, Cr, Hg or Cd are not required by plants and show phytotoxic effects even at low concentrations. Although the environmental risk of high HM concentrations in composts is dependent on the chemical form of the element, toxicity limits for available or mobile HM concentrations in composts are not still established. Therefore, regulations on HM concentrations in compost are referred to total HM concentration. The total Zn and Cu concentrations (Table 4) in MSWC were over the limits proposed by the Spanish regulation for compost (RD 824/2005, BOE 171) (Spanish State 2005), which limits the concentrations of Zn and Cu to 1000 and 400 mg kg^{-1}, respectively, for the lower quality class C compost (although this regulation does not strictly apply to growing media). Zn and Cu concentrations in MSWC, as well as in MGSS, also exceeded the more stringent limits provided in the Working document on Biological treatment of biowaste (second draft) (ECC 2001), that restricts the concentrations of Zn and Cu to 400 and 200 mg kg^{-1}, for Class 2 compost. However the US legislation (USEPA 40 CFR Part 503 (USEPA 1994) proposed that concentrations of Zn and Cu in compost have to be lower than 1500 and 2800 mg kg^{-1}. Therefore, high concentrations of Zn and Cu could be considered a temporary limitation to the commercialization of MSWC in Spain,

Table 5: Physical properties of substrates.[1]

Substrate	Dry bulk density (kg m^{-3})	Particle density (kg m^{-3})	Shrinkage (%)	Total pore space (%)	Water volume at −10 cm (%)	Air space (%)
MSWC	364c	2066b	29a b	82d	48c	34b
MSGW	420d	2032b	22a	79c	54d	25a
MGSS	435d	1941b	26a b	78b	54d	24a
MV	586e	2092b	22a	72a	37a	35b
CPB	186b	1563a	43b	88e	42b	46c
PB	175b	1570a	32a b	89e	42b	47c
Peat	108a	1558a	23a	93f	49c d	44c
Optima values[2]	< 400	1400–200	< 30	> 85	55–70	20–30

For definition of abbreviations see Table 1.
[1]Values are the means of three determinations and different letters in each column indicate significant differences as determined by the Tukey test at $P < 0.05$
[2]Optima physical properties of an ideal substrate for plant growth according to De Boodt & Verdonck (1972); Verdonck & Gabriëls (1988) and Abad *et al.* (2001)

and could be overcome once the separation of organic waste at the origin is better established.

With regard to the different extraction process, $CaCl_2$ + DTPA extracted higher concentrations of HM than water, but in both cases the concentration of easily released HM (Table 4) was several times lower that the concentration of total HM extracted with *aqua regia*. Among the potentially toxic metals, Cu, Zn and Pb showed the highest concentrations in $CaCl_2$ + DTPA extracts. In particular, Pb showed the highest extraction rate, when compared with its total concentration in compost, suggesting a higher mobility and potential environmental risk of this element. The high total concentration and high availability of Zn in the manure compost MV should also be noted. Statistically, MSWC had the same concentration of Fe, Mn, Cd, Cr and Ni extracted in *aqua regia*, as MGSS, but showed the highest concentrations of Fe, Mn, Cu, Zn, Pb and Ni extracted in $CaCl_2$ + DTPA, whereas CPB, PB and peat had statistically equivalent concentrations of HM, although in all the cases, the concentrations of HM extracted in *aqua regia* were much higher than the concentrations extracted in water or $CaCl_2$ + DTPA.

Physical analysis

The physical properties are also important contributors to the quality of compost as a component of growing media, particularly those related to the water-holding capacity and air supply. So, the optimum physical properties of an ideal substrate for plant growth are: high water-holding capacity, low bulk density, high porosity, fine texture and a stable structure (De Boodt & Verdonck 1972, Verdonck & Gabriëls 1988). Table 5 shows the physical properties of MSWC compared with the other substrates as well as the optimum values proposed by several authors (De Boodt & Verdonck 1972, Verdonck & Gabriëls 1988, Abad *et al.* 2001). MSWC had particle density values of about 2000 kg m^{-3}, which was close to the values for MSGW, MGSS and MV, whereas lower values were obtained for CPB, PB and peat. On the other hand, MSWC had acceptable values of bulk density, which were higher than those of PB, CPB and peat, but lower than those of MSGW, MGSS and MV. The shrinkage values were in the acceptable range for all the growing media (< 30%) except for CPB (43%). Total pore space data show that MSWC contained a higher pore space, which was available for water and air retention, than MSGW, MGSS and MV but less than peat, CPB and PB. Although the total porosity was lower for MSWC than for peat, CPB and PB, the water content at a suction of −10 cm was higher in MSWC than in CPB and PB, and close to the value for peat. At −10 cm suction, pores that contain water are smaller than 300 µm (Clemmensen 2004), whereas the rest were filled with air. The higher water content at −10 cm indicated that peat, MSGW and MGSS contained a larger amount of smaller pores than the other more open types of composts (MV, CPB, PB and MSWC).

With the exception of particle density, MSWC had values for the physical properties that were in the middle of the range for the other substrates. Nevertheless, in order to obtain optimum physical properties MSWC could be diluted with CPB or peat. Thus, after mixing MSWC with 25% or 75% peat or CPB some physical properties of the substrate were improved (Table 6). From the physical point of view the best properties were observed in mixtures with 25% peat or CPB, which showed equilibrium between increased porosity and water/air retention characteristics. These results are in agreement with those found by Sánchez-Monedero *et al.* (2004), which showed that compost mixtures with peat resulted in lighter media with higher porosity and improved air/water balance, together with higher total and available water-holding capacity.

Table 6: Physical properties of municipal solid waste compost (MSWC) diluted with composted pine bark (CPB) or peat.[1]

	75% MSWC, 25% Peat	75% MSWC, 25% CPB	25% MSWC, 75% Peat	25% MSWC, 75% CPB
Dry bulk density (kg m^{-3})	230b	301c	128a	249b
Particle density (kg m^{-3})	1912b	1913b	1660a	1664a
Shrinkage (%)	23b	16a	26c	21b
Total pore space (%)	88b	84a	92c	85a
Water volume at –10 cm (%)	55d	51c	37a	43b
Air space (%)	33a	33a	55c	42b

[1]Values are the means of three determinations and different letters in each column indicate significant differences as determined by the Tukey test at $P < 0.05$.

Plant tolerance study

According to FCQAO (1994) recommendations, compost is considered to be plant tolerant if no visible chloroses or necroses appear on the leaves, and the fresh mass yield of the tested substrate with 25% compost proportion reaches at least 90% of the yield of the comparison substrate. Figure 2 shows the relative yield of spring barley in the mixtures with 25% composted substrates, with respect to the comparison substrate. All the composted substrates reached yields higher than 90% of that of the comparison substrate, and no visible plant damage was detected. This means that the composts can be used as a soil improver and fertilizer (FCQAO 1994). In order to determine whether the composted substrates can be used as blending components for growing media, the comparison substrate was mixed with 50 % of the composted substrates. As can be seen in Figure 3, CPB, MSGW, MGSS, and MV can be recommended as substrates, whereas MSWC could only be employed as a soil improver, because it did not reached a 90% fresh mass yield of the reference substrate. The low plant tolerance in the barley test using 50% MSWC could be due to an excess of salt content. As indicated above, MSWC did not present acceptable EC values (Table 2), according to the limits proposed by Abad *et al.* (2001). Moreover, when MSWC was leached with water some better biological results were obtained (data not shown), confirming that the excess of salt inhibited plant growth. On the other hand, it is important to mention that the plant tolerance test was carried out using a comparison substrate consisting in peat and perlite. This reference substrate was probably richer in nutrients than the comparison soil proposed by the FCQAO (1994), and in consequence the results obtained during the plant tolerance test were probably compared too strictly.

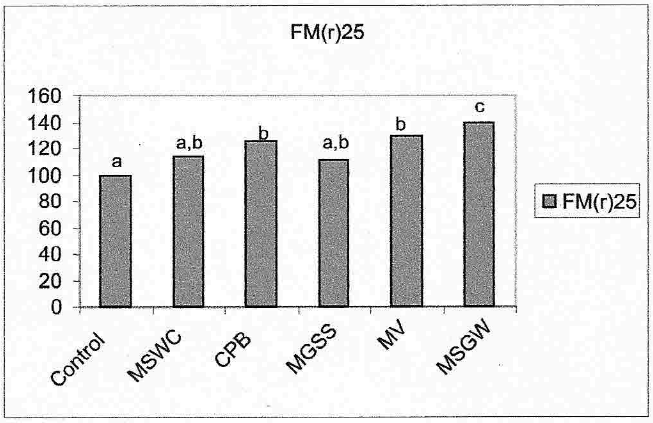

Fig. 2: Relative yield of spring barley in the mixtures with 25% composted substrates, with respect to the comparison substrate. For definition of abbreviations see Table 1.

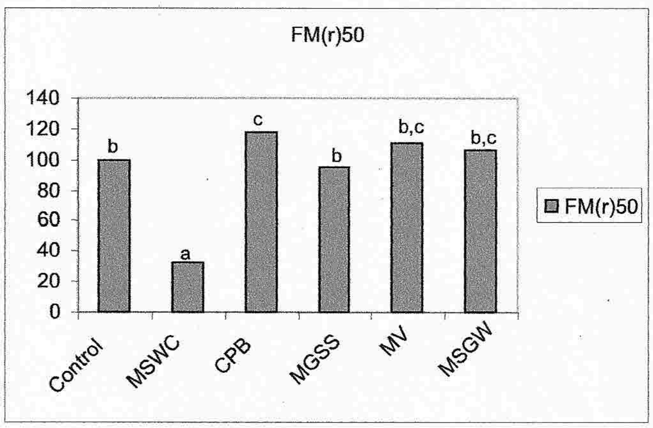

Fig. 3: Relative yield of spring barley in the mixtures with 50% composted substrates, with respect to the comparison substrate. For definition of abbreviations see Table 1.

Conclusions

Aerobic municipal solid waste compost (MSWC) from Galicia (Spain) obtained on an industrial scale was compared with other available commercially composted substrates, for its potential use as soil amendment or a plant substrate component. MSWC presented higher available nutrient concentrations than commercial *Sphagnum* peat and similar levels to other composted substrates such as composted green waste or vermicomposted manure. With respect to the heavy metal concentrations, Zn and Cu in MSWC were over the limits proposed by the Spanish regulation for compost, showing that source separation was not efficient. Taking into account the physical properties and the electrical conductivity of MSWC, improvement could be obtained by diluting MSWC with peat or composted pine bark. The results of the plant tolerance test suggest that MSWC could be employed as soil amendment and fertilizer; whereas the other substrates tested could also be used as plant substrates for potted plant production. In order to improve the quality of MSWC it would be necessary to improve the separation at source of the urban organic waste.

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