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Composting of wine industry wastes and their use as a substrate for growing soilless ornamental plants

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Abstract

To study the process of composting of grape marc and test the resulting compost as a substrate for the cultivation of ornamental plants, six composting processes, with mixtures of dealcoholised grapevine marc and grape stalk (DM + GS) in a 1:1 ratio (v:v), were carried out in Seville (Spain) between 2000 and 2006. The duration of the composting ranged between 20 and 24 weeks in the Spring-Summer season. Weekly, temperature, pH, EC, $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$, were measured. The maximum temperatures reached values of 65-73°C at a depth between 40 and 80 cm. The compost had a slightly alkaline pH, slightly salinity, high organic matter and total nitrogen contents. The final compost chemical composition in total elements showed values in the same range as those corresponding to plant material, except for Fe. The distribution in the size of the particles gives way to a total porous space that is close to the one considered as optimal in a substrate for soilless cropping. Pore size distribution showed a prevalence of big pores that produces unbalance in the water-air ratios, resulting in a material with a good aeration but with low water retention. The composts were tested as substrates for four ornamental species: geranium, petunia, carnation and gerbera. The results suggest that compost has no limiting characteristics for its use as a medium for the cultivation of ornamental plants in container, and can replace conventional substrates, such as peat and coconut fibre.

Additional key words: compost; grape marc; growing media; soilless culture.

Resumen

Compostaje de residuos de la industria vinícola y su uso como sustrato para el cultivo sin suelo de plantas ornamentales

Para estudiar el proceso de compostaje de orujos de uva y probar el compost resultante como sustrato para el cultivo de plantas ornamentales, se llevaron a cabo, en Sevilla (España) entre 2000 y 2006, seis procesos de compostaje, con mezclas de orujos de vid desalcoholizados y tallos de vid o raspón (DM + GS) en una proporción 1:1 (v:v). La duración del compostaje osciló entre 20 y 24 semanas en el período de primavera-verano. Se midieron semanalmente temperatura, pH, CE, $N\text{-}NO_3^-$ y $N\text{-}NH_4^+$. Se alcanzaron temperaturas máximas de 65 a 73°C a 40-80 cm de profundidad. El compost resultante tenía pH ligeramente alcalino, moderada salinidad, altos contenidos en materia orgánica y nitrógeno total. Los análisis químicos del compost mostraron niveles de elementos totales en igual rango que los correspondientes a material vegetal, excepto Fe. La distribución del tamaño de partículas del material origina un espacio poroso total cercano al considerado óptimo en los sustratos para cultivo sin suelo. La distribución del tamaño de poros mostró una prevalencia de poros grandes, circunstancia que produce un desequilibrio en las relaciones aire-agua, dando como resultado un material con buena aireación, pero con baja retención de agua. Los composts se probaron como sustratos para cuatro especies ornamentales: geranio, petunia, clavel y gerbera. Los resultados no sugieren ninguna característica limitante para el uso del compost como medio para el cultivo de plantas ornamentales en contenedor, y puede sustituir a los sustratos convencionales como la turba y la fibra de coco.

Palabras clave adicionales: compost; orujo de vid; medio de cultivo; cultivo sin suelo.

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Abbreviations used: CEC (cation exchange capacity); CF (coconut fibre); DM (dealcoholised marc); EAW (easily available water); EC (electrical conductivity); GI (germination index); GM (grape marc); GS (grape stalk); L (wine lees); NDI (N drawdown index); P (peat-based commercial substrate); SM (spent mushroom compost).

Introduction

Spain produces over 5 billion litres of wine yearly (Bustamante, 2007), thus generating a considerable amount of wastes: 364,000 t of grape stalk (GS), involving the peduncles and the main stems of racemes, 10^6 t of marc (GM), comprising the rest of the grape's skin, pulp and seeds, 437,000 t of wine lees (L) or sediments remaining after the fermentation of the wine components, and 31×10^6 m^3 of waste water (Bustamante, 2007; Cegarra & Paredes, 2008). According to the European Union, the GM and L must be delivered to the distilleries for the obtainment of alcohol and the extraction of tartrates; after this, a solid waste remains, the so-called exhausted or dealcoholised marc (DM), plus a liquid one, vinasse.

The characteristics of fresh GS, GM, L and DM have been studied by Bustamante *et al.* (2008a). As a general rule, they are characterised by an acid pH, a low electrical conductivity and high content of organic matter. In addition, GS and seeds coats have a very high C/N ratio due to their lignocellulosic nature. The contents of polyphenols are highly variable, especially in GS, between 3.8 and 34.9 g kg^{-1}, and low in DM, between 1 and 3.5 g kg^{-1}. These differences are probably due to the fact that GS evidence a greater content of readily extractable tannins and that most of the phenolic compounds in marc are lost during its leaching at the distilleries for the extraction of the alcohol and tartrates contained therein. Also the seed coats are rich in tannins. Significant contents of N, P and K are to be noted, especially in L, which are mainly due to the fact that this waste contains protein clarifiers that are added to wine, as well as yeasts and ferric phosphate and potassium bitartrate salts (Cegarra & Paredes, 2008).

Some of the environmental problems generated by the wastes of the wine industry derive from the concentration of its production in a short period (August-October), from its acid character and its high content of phenolic substances, with phytotoxic and antimicrobial effects.

A good number of studies have been made on the use of such wastes in agriculture, generally after their composting in mixtures with other wastes, and on the beneficial effects of these composts as organic fertilisers and in soil amendments (Madejón *et al.,* 2001 and 2002; Ranalli *et al.*, 2001; Díaz *et al.*, 2002; Bertrán *et al.*, 2004; Patti *et al.*, 2004; Rodríguez *et al.*, 2006; Bustamante, 2007; Moldes *et al.*, 2007; Bustamante *et al.*, 2008b). Descriptions have also been made of the suppressive character of wine industry waste composts against soil phytopathogens (Borrero *et al.*, 2004, 2006, 2009, Segarra *et al.,* 2007, Trillas *et al.*, 2006). However, lesser references are available concerning their characterisation and utilisation as peat substitutes in soilless growing media (Reis *et al.*, 1998).

The aim of this paper is to study the process of composting DM and GS mixtures, performing characterisation of the obtained composts for their use as substrate, and appraising their suitability for the ornamental plants production in containers.

Material and methods

Composting

Six composting processes, with mixtures of dealcoholised grapevine marc and grape stalk (DM + GS) in a 1:1 ratio (v:v), were carried out in Seville (Spain) between 2000 and 2006. The composting procedure was applied in windrows kept at the open air, with periodical turnovers every 7-15 days. The piles had a trapezial section with a 3.5 m base, 2 m high and volumes ranging between 40 and 50 m^3. The duration of the composting ranged between 20 and 24 weeks in the Spring-Summer season.

Initially, DM + GS mixtures were fertilised with N, P, Mg and Fe, with the doses varying throughout the years between 2-2.5 kg.m^{-3} of ammonium nitrate, 1.25-2 kg.m^{-3} of superphosphate (18% P_2O_5) and 0.6-1.2 kg.m^{-3} of magnesium sulphate and iron sulphate. Further on, mineral N was added when exhaustion in the pile was detected. Water content was kept above 40% by sprinklers on top of the piles. Weekly, temperature was measured at half height on both sides of the pile, at 20, 40, 60, 80, 100 and 120 cm in depth. Waste subsamples were taken in 6 different areas and at depths between 20 and 80 cm, according to sampling rules of ECS (2001, 2002). An aliquot of the mixture of these sub-samples was analysed in duplicate in order to control the evolution of the process. The pH, EC (electrical conductivity), N-NO_3^- and N-NH_4^+ were determined on compost/water extracts 1:2 (v:v), N-NO_3^- and N-NH_4^+ were measured by reflectometry with RQflex 10 colorimeter by Merck. The organic matter (OM) was determined by weight loss after ashing at 550°C. Total N was determined by means or the Kjeldahl or Dumas method (as described by Bremner, 1996) depending on the year, while the Harada & Inoko's method (1979) was used for cation exchange capacity (CEC).

Compost characterisation

The composts were analysed after 20-24 weeks composting. The sampling was performed as described above.

Their physical properties were determined in compliance with the standards for analysis of amendments and growing media (ECS, 2001, 2002), except for the particle density that, considering the buoyancy of the material, was performed by submersion (Ordovás *et al.*, 1996).

Conventional methods were used for their elementary composition: organic C by the Walkley and Black method; total N by the Dumas method; total phosphorus according to Murphy & Riley (1962); and the rest of the total elements by atomic emission/absorption spectrometry.

The assimilable elements were analysed in 1:5 (v/v) suspensions, using water to extract N and phosphorus, ammonium acetate for K, Ca and Mg extraction, and DTPA-$CaCl_2$ for the metallic microelements. In the corresponding extracts, N was measured by reflectometry, phosphorus as per Murphy & Riley (1962), and the rest of the elements by atomic emission/absorption spectrometry.

The germination indexes (GI) were calculated for the detection of phytotoxicity in growing media, using lettuce seeds and sand as a control substrate (Ortega *et al.*, 1996). The N drawdown index (NDI_{150}) of the composts was measured (Handreck, 1992) The NDI measures the ratio between mineral N remaining in composts samples after 4 days of incubation, and the initial N. The microbial activity was estimated by assessing β-glucosidase activity (Bandick & Dick, 1999).

Agricultural evaluation

The DM + GS composts were tested as substrates for four ornamental species: geranium (*Pelargonium × Hortorum* Bailey), petunia (*Petunia hybrida* Hort.), carnation (*Dianthus caryophyllus* L.) and gerbera (*Gerbera jamesonii* Bolus). The control substrates varied depending on the species: for petunias, geraniums and gerberas, a peat-based (P) commercial substrate was used alone, and with a mixture of spent mushroom compost in ratio 1:1 (v:v) (SM + P). For carnations, coconut fibre (CF) and (SM + P) were used as controls.

Before transplanting, all the substrates were irrigated and fertilised with Osmocote (slow-release fertiliser: 15-10-12 + 2 MgO + micronutrients, from Scotts Int. Co.) at a dose of 4 g L^{-1}. Additionally, before transplanting the carnations, a PG-mix (soluble fertiliser: 12-14-24 + micronutrients, from Yara Int. Co.) was added at a dose of 1 g L^{-1} of substrate and, before transplanting the gerbera, Peters Professional (soluble fertiliser: 20-10-20, from Scotts International Company) was used at 1 g L^{-1} of substrate. The tests were carried out in Seville, under a polyethylene greenhouse, without any heating and in 2-L containers. Irrigation was applied by pouring, once or twice a week.

For each test a completely randomized design was conducted, with 6 replications per substrate. The duration of the tests ranged between 75 days for carnations and 150 days for gerbera. When tests were finished, various vegetative variables and the mineral composition of the aerial part were measured. Additionally, for gerbera and carnation, the green colour intensity of leaves, related to chlorophyll content, was measured using a Minolta SPAD-502 chlorophyll meter.

The statistical analysis was performed by ANOVA. The means were compared using Tukey's test ($p < 0.05$).

Results and discussion

Composting

The presence of phenolic substances in the fresh wastes did not seem to hinder microbial activity in the windrows. In the 6 processes involved the thermophilic phase was reached after very few days (Fig. 1). A maximum temperature of 65 to 73°C were registered at 40 through 80 cm depth. High temperatures remained above 45-50°C for about 20 weeks, then decreasing very slowly to about 40°C at week 24, when we terminated the process. This means that some of the material was still in the active phase of decomposition of the cellulosic fraction and, therefore, is not fully biologically stabilized.

Other researches have described rapid increases and sustained high temperatures during thermophilic composting of GS (Reis *et al.*, 1998) and of other DM mixtures with manure (Bustamante *et al.*, 2008b). However, the latter authors perceived a clear inhibition of the thermophilic phase with a fast cooling when the mixture contained GS, attributing this phenomenon to

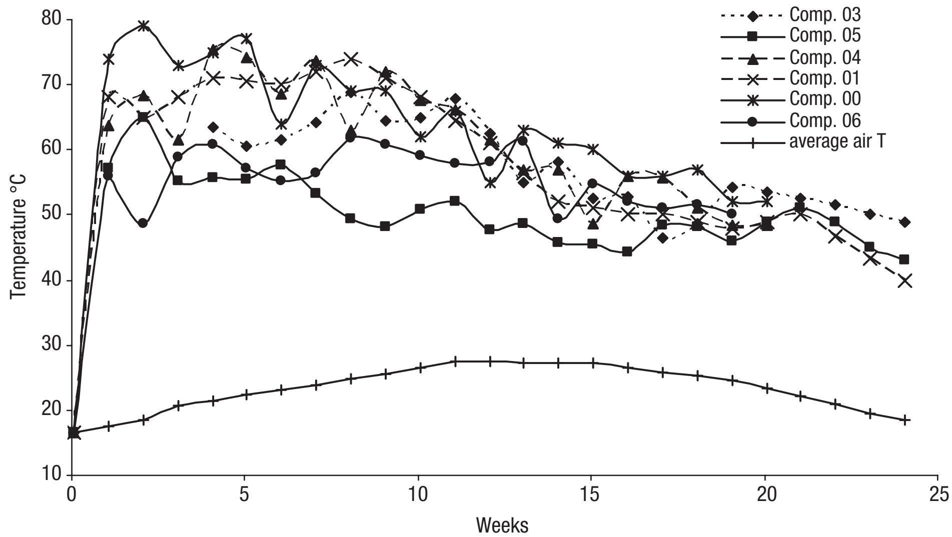

Figure 1. Temperature evolution between 40 and 80 cm depth of the six composting processes, between 2000 (comp. 00) and 2006 (comp. 06), of mixtures of dealcoholised grapevine marc (DM) and grape stalk (GS).

the high GS content of polyphenols that might slow down microbial activity. Probably, as in other lignocellulosic materials, the high C/N ratio in GS and the scarce assimilable N content of the piles did also have an influence and, therefore, addition of some soluble N source to these wastes appears to be advisable when GS is present in the mixtures.

The weekly controls of some physical and chemical variables showed small differences among the 6 processes under study (Table 1). Water content showed slight ups and downs as a result of the evaporation and irrigation cycles, and remained permanently above 40%; pH tended to rise slightly, although also with small fluctuations due to successive proteolysis processes leading to the formation of NH_3 and to further nitrification. The absence of acidifications plus the high temperatures in the piles would be clear indicators the aerobic conditions predominant in the piles throughout the whole process. Other authors have obtained similar pH values, in the vicinity of 7.5, for these composts (Reis *et al.*, 1998; Patti *et al.*, 2004; Bustamante *et al.*, 2008a); the final value may depend on the nature and proportion of the wastes present in the mixture; thus, Bustamante *et al.* (2008a) obtained composts with pH > 8 when DM was mixed with poultry manure.

Salinity showed differences among the six processes studied because the dates of reposition of N-fertiliser were different for each one of them. In every case, the windrows evidenced strong fluctuations in

Table 1. Evolution of some physical and chemical variables during the composting of mixtures containing dealcoholised grapevine marc and grape stalk (DM + GS)

Week	Water content (% fresh weight)		pH		EC (dS m^{-1})		OM (%)		Total N (%)		CEC (cmol kg^{-1})
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean
1	58	6.2	6.95	0.33	1.93	0.58	91.9	0.98	2.14	0.04	99.10
5	56	3.2	7.39	0.17	1.20	0.16	89.6	1.85	2.25	0.02	109.13
10	46	5.0	7.47	0.20	2.36	0.56	82.0	5.32	2.24	0.02	118.29
15	53	2.7	7.62	0.14	1.26	0.20	79.1	5.74	2.16	0.05	118.59
20	43	4.4	7.35	0.14	1.63	0.28	75.2	5.40	2.35	0.17	121.10

n = 6 for water content, pH, electrical conductivity (EC) and total N; n = 3 for organic matter (OM); n = 1 for cation exchange capacity (CEC). SE: standard error.

EC, with fast increases after the addition of ammonium nitrate and the further nitrification of ammonium, as well as decreases at a far slower rate as the mineral nitrogen was immobilised by microorganisms (data not shown). The mean EC value was in the range found in previous works: from less than 1 dS m^{-1} (Reis *et al.*, 1998; Moldes *et al.*, 2007) to values exceeding 2.5 dS m^{-1} (Patti *et al.*, 2004; Bustamante *et al.*, 2008b). These variations are due to differences in composition, piles management and the degree of maturity attained by the compost. Thus, Bustamante *et al.* (2008b) obtained composts with EC > 5 dS m^{-1} when the windrow was irrigated with vinasse.

The observed reduction in OM would be justified by the oxidation of readily decomposable carbon contained in the grape's skin and pulp, which are rich in sugar and poor in cellulose. The final compost contains a significant proportion of seeds and grape stalks, little altered during the process because of their lignocellulosic nature. This allowed the OM content to stay above 70%, with a C/N ratio of 15.5-18 (Table 2), values that are also similar to those obtained by other authors in composts from these wastes (Reis *et al.*, 1998; Baran *et al.,* 2001; Patti *et al.,* 2004; Moldes *et al.,* 2007). The total nitrogen content in the final compost (Nt) was within the interval (2-3%) described by the aforementioned authors and by Baran *et al.* (2001) and Flavel *et al.* (2005).

The recorded increase of CEC would be related to the increase in the proportion of humic substances developed as decomposition evolved. When measuring the content of these substances in composts from wine industry wastes, Patti *et al.* (2004) reported a humic and fulvic acids low content, as opposed to high contents (above 60%) of humines. The final values of CEC were in the same range as those obtained by Reis *et al.* (2003), although definitely lower than the ones obtained by Bustamante *et al.* (2008b) with different mixtures of GS, GM, DM and manures. Even though the CEC measured by Harada & Inoko (1979) has been accepted as an indicator of compost maturity, its optimal value depends to a great extent on the nature of wastes. Thus, Harada & Inoko (1979) recommended values ranging between 60 and 80 cmol kg^{-1} for confirming maturity in composts from urban wastes. However, these values are in the same range as or even lower than those obtained by our group and by Reis *et al.* (2003) and Bustamante *et al.* (2008b), in yet-non-composted wine industry wastes.

Table 2. Composition of total elements (on dry weight basis) in final composts samples from mixtures of dealcoholised grapevine marc and grape stalk (DM + GS)

Elements	Mean	Range	CV (%)[a]
C (%)	40	31.7-44.9	18
C/N	17	15.5-18.2	9
Nt (%)[b]	2.35	1.78-2.8	18
P (%)	0.39	0.24-0.48	32
K (%)	0.81	0.28-1.32	65
Ca (%)	2.70	0.20-4.60	83
Mg (%)	0.39	0.24-0.61	51
Na (%)	0.02	0.01-0.03	44
Fe (mg kg^{-1})	4,017	3,052-5,835	39
Mn (mg kg^{-1})	127	86-176	26
Cu (mg kg^{-1})	25	18-31	27
Zn (mg kg^{-1})	41	36-49	36
B (mg kg^{-1})	54	40-68	37

[a] CV: coefficient of variation. [b] Nt: total nitrogen.

Compost characterisation

The final compost chemical composition in total elements (Table 2) shows values in the same range as those corresponding to plant material, except for Fe. Other authors have also measured high contents of this element: 0.2-0.6% (Patti *et al.*, 2004), 0.1-0.9% (Bustamante *et al.*, 2008b), and they might be justified by the particular handling and chemical treatment of the wastes in wineries and distilleries for the cleaning of barrels, extraction of Ca and K tartrates, etc. To this effect, Cegarra & Paredes (2008) reported the application of ferric phosphate salts.

The high variability observed in the composition of some elements in the DM+GS composts (Table 2) might result from the original composition of the fresh wastes. Thus, in the analysis of 87 samples collected from diverses wineries and distilleries in Spain, Bustamante *et al.* (2008a) detected a high variability in their chemical composition. This variability could be due to particular handling of fresh wastes in the wine industry and to edaphic, climatic and agricultural characteristics of the region of origin of the grapes. Finally, the method used for preparing the compost may also have had an influence. In our case, the greater contents of alkaline and alkaline earth elements were found in the processes performed on natural soil, where some earth was added during the turnover. The lowest ones were found in composting carried out on paved soil.

The pH or EC values and the mean concentration of assimilable elements in DM + GS composts (Table 3) do not constitute limiting factors for using as substrates for soilless cropping, as they are within, or close to, the intervals considered as optimal for such purpose (Abad *et al.*, 1992; Carmona & Abad, 2008). Only the NO_3^- content, which depends on the time elapsed since the last application of N-fertiliser to the windrow, and those of soluble phosphorus is low. On the other hand, the contents of K and Ca are quite high. However, the wide range of variation in the concentrations of all the assimilable nutrients and the practical difficulty of analysing each one of the composts before their use by the farmers would advise the utilisation of a preplant fertilizer in order to ensure a balanced nutrition of the plants.

Table 3 also shows the values for some important biological features. The immobilising capacity of N (NDI), related to the maturity of the compost, decreased during composting, as a reduction took place in the availability of readily oxidisable carbon compounds, such as starch and free cellulose. Thus, NDI increased from 0.01 in the fresh wastes (data not shown) to a mean value of 1.1 in the final composts. According to Handreck (1992), NDI values between 0.8 and 1 would indicate a significant absence of N immobilisation, while those above 1 would imply the existence of a net nitrification. β-glucosidase activity, correlated with microbial activity, showed values similar to observed by Segarra *et al.* (2007) in these materials. Borrero *et al.* (2006) found that microbial activity in DM+GS composts is relatively high compared to the usually found in peat and coconut fibre substrates. The microbial activity of composts has been positively correlated with the suppressiveness to tomato and carnation fusarium wilt (Borrero *et al.*, 2004, 2009).

Table 3. Characteristics and contents of assimilable elements of dealcoholised grapevine and grape stalk compost (DM + GS) used as a substrate

	Mean	Range	CV (%)[a]
pH	7.35	6.98-7.78	5
EC (dS m^{-1})[b]	1.63	0.69-2.31	42
NO_3^- (mg L^{-1} substrate)[b]	230	44-372	78
P (mg L^{-1} substrate)	22	8-44	83
K (mg L^{-1} substrate)	1,853	1,465-2,375	20
Ca (mg L^{-1} substrate)	5,605	1,697-11,745	78
Mg (mg L^{-1} substrate)	633	335-910	37
Fe (mg L^{-1} substrate)	45	24-69	51
Mn (mg L^{-1} substrate)	8	3-11	57
Cu (mg L^{-1} substrate)	0.52	0.3-0.8	55
Zn (mg L^{-1} substrate)	5	3-9	73
GI (%)[c]	101	98-108	4
NDI[d]	1.1	0.72-1.53	35
β-glucosidase activity (µg hydrolyzed *p*-nitrophenol cm^{-3} h^{-1})	110.8	76.5-148.9	17

[a] CV: coefficient of variation. [b] EC and the contents of soluble N will depend on the time elapsed after the last application of a mineral fertiliser to the windrow. [c] GI: germination indexes. [d] NDI: nitrogen drawdown index.

Furthermore, the absence of phytotoxicity becomes essential when the compost is going to be used as a substrate. Probably, the already mentioned high content of tannins and polyphenols in GS and in the seeds coats were responsible for the fact that GI did not exceed 13% in the fresh wastes (data not shown). These GI reached values approaching 100% 2.5-3 months after composting was started (Table 3). Similar increases in this index were obtained by Moldes *et al.* (2007) and Reis *et al.* (1998) when wine industry wastes were composted, which would confirm the effectiveness of the composting process in the destruction of organic phytotoxins.

As a general rule, the physical features of DM+GS composts are more homogeneous than the chemical ones. Their appearance is similar to that of fine gravel. Their granulometric distribution (Table 4) shows that, as an average, almost half of the particles are sized above 2 mm. These thick particles result mostly from the seeds, which are scarcely altered during composting, and to some identifiable grape stalk remains. The particle size of the medium affects the size and distribution of the pores, air and water relationships (Carmona *et al.* 2003a), and hidrological properties of container media (Carmona *et al.*, 2003b). The distribution of particle size in DM + GS gives way to a total porous space (Table 5)

Table 4. Distribution of particle size (Ø, mm) in dealcoholised grapevine and grape stalk compost (DM + GS)

	> 2	2-1	1-0.5	0.5-0.25	0.25-0.125	0.125-0.625	< 0.625
Mean	46.7	14.5	14.9	12.6	7.0	3.1	1.2
Range	41-60	3-18	11-20	11-13	6-8	2-4	0.8-2
CV (%)[a]	15	42	22	7	12	18	41

[a] CV: coefficient of variation.

Table 5. Physical properties of dealcoholised grapevine and grape stalk compost (DM + GS) used as a substrate

Property[a]	Units	Mean	Range	CV (%)[b]	Optimal range[c]
ρa	(g cm^{-3})	0.32	0.2-0.39	20.3	< 0.4
ρr	(g cm^{-3})	1.68	1.52-1.82	6.7	1.45-2.65
PS	(%)	80.00	75.5-87.8	4.5	> 85.0
Θcc	(% v:v)	60.22	55.02-63.90	5.7	
BDcc	(g cm^{-3})	0.30	0.20-0.38	19.2	
A	(% v:v)	27.4	19.9-40.2	19.6	20-30
Water retention at:					
-1 kPa	(% v:v)	53.2	45.9-59.2	6.8	55-70
-5 kPa	(% v:v)	40.6	35.3-46.3	7.9	31-40
-10 kPa	(% v:v)	38.9	34.0-44.5	8.5	25-31
EAW	(% v:v)	12.7	8.3-21.2	27.8	20-30
RW	(% v:v)	1.6	0.6-2.8	38.8	4-10

[a] bulk density (ρa), particle density (ρr), effective porous space (PS), container capacity (Θcc), bulk density at container capacity (BDcc), aeration capacity (A), easily available water (EAW), reserve water (RW). [b] Coefficient of variation (CV), n = 32. [c] Optimal range (Carmona & Abad, 2008).

that is close to the one considered as optimal in a substrate for soilless cropping (Abad *et al.*, 1992; Carmona & Abad, 2008). However, pore size distribution shows a prevalence of big pores that produces unbalance in the water-air ratios, resulting in a material with good aeration capacity (A) but with low water retention, and a content of easily available water (EAW) that is approximately half of the one considered as optimal (Abad *et al.*, 1992; Carmona & Abad, 2008). This disadvantage can be overcome through proper proportion in mixtures with conventional substrates, and the adjustment of the dose and frequency of irrigation to the characteristics of these mixtures.

Agricultural evaluation

The growth of the four ornamental species planted on DM + GS was satisfactory; no significant differences were found in the explored vegetative variables compared with the reference substrates P, SM + P or CF (Tables 6 and 7). Only the chlorophyll content SPAD values were significantly higher in the gerbera plants grown on P. Both the complete plants and the flowers of petunia, geranium and gerbera reached commercial quality. The carnations test was discontinued before they reached the flowering stage.

In some cases, nutrient content in the aerial part of the plants grown on DM + GS were significantly different from those corresponding to the control substrates (Tables 8 and 9). The K contents in all species were higher in plants grown in DM + GS than in P + GS, and similar to those grown in SM + P. Nevertheless, these differences did not seem to have an influence upon the growth variables under study, as reflected in Tables 6 and 7.

The only references found on the mineral composition of ornamentals plants are Mills & Jones (1996) or Reuter & Robinson (1997), which correspond to leaf analysis. In this study, we have analyzed the aerial part of the plant; therefore, even accepting this limitation, we use these values as reference. The plants grown on DM + GS composts are within, or very close to, the aforementioned sufficiency intervals. Only N in gera-

Table 6. Vegetative variables in petunia and geranium grown on dealcoholised grapevine and grape stalk compost (DM + GS); commercial substrate based on peat (P); spent mushroom compost plus peat (1:1; v:v) (SM + P)

Substrate	Stem (number)	Flowers (number)	Dry weight (g)	Plant height (cm)
Petunia				
DM + GS	11.5 a	107.0 a	43.04 a	–
P	13.8 a	117.8 a	47.89 a	–
SM + P	12.2 a	88.8 a	49.34 a	–
Geranium				
DM + GS	12.7 a	6.8 a	35.12 a	32.1 a
P	16.2 a	11.3 a	46.41 a	33.8 a
SM + P	10.5 a	4.0 a	34.90 a	35.3 a

In each column and for the same species, values followed by the same letter are not statistically different according to the Tukey test at $p < 0.05$.

Table 7. Vegetative variables in gerbera and carnation grown on dealcoholised grapevine and grape stalk compost (DM + GS); commercial substrate based on peat (P); coconut fibre (CF) ; spent mushroom compost plus peat (1:1; v:v) (SM + P)

Substrate	Peduncle length (cm)	Plant height (cm)	Flowers (number)	Dry weight (g)	Inflorescence diameter (cm)	Chlorophyll (SPAD)
Gerbera						
DM+GS	33.7 a		4.6 a	34.0 a	8.4 a	48.4 a
P	30.9 a		6.1 a	28.0 a	8.1 a	57.2 b
SM+P	36.1 a		5.7 a	33.1 a	8.0 a	49.6 a
Carnation						
DM+GS		30.29 a		13.45 a		46.65 a
CF		32.17 a		15.93 a		51.50 a
SM+P		31.29 a		15.77 a		48.18 a

In each column and for the same species, values followed by the same letter are not statistically different according to the Tukey test at $p < 0.05$.

Table 8. Content of nutrients in the aerial part of petunia and geranium plants grown on dealcoholised grapevine and grape stalk compost (DM + GS); commercial substrate based on peat (P); spent mushroom compost plus peat (1:1; v:v) (SM + P)

Nutrients	Petunia			Geranium		
	DM + GS	P	SM + P	DM + GS	P	SM + P
N (%)	2.81 a	3.83 a	3.28ab	2.14 b	2.66 a	2.40 ab
P (%)	0.38 b	0.23 a	0.30 ab	0.23 a	0.19 a	0.23 a
K (%)	3.91 b	1.16 a	3.82 b	2.70 b	1.11 a	2.98 b
Ca (%)	2.35 a	1.77 a	2.37 b	1.04 a	0.78 a	1.43 b
Mg (%)	0.38 ab	0.31 a	0.47 b	0.23 b	0.16 a	0.19 ab
Na (%)	0.62 a	1.69 b	1.19 ab	0.29 a	0.81 b	0.16 a
Fe (mg kg^{-1})	128 a	296 b	109 a	126 a	383 b	71 a
Mn (mg kg^{-1})	81 a	83 a	58 a	80 a	26 a	14 a
Cu (mg kg^{-1})	2 a	5 ab	6 b	7 a	2 b	5 a
Zn (mg kg^{-1})	39 a	57 a	49 a	24 a	17 a	23 a
B (mg kg^{-1})	22 a	34 a	25 a	24 a	22 a	26 a

In each row and for each species, values followed by the same letter are not statistically different according to the Tukey test at $p < 0.05$.

Table 9. Content of nutrients in the aerial part of gerbera and carnation plants grown on dealcoholised grapevine and grape stalk compost (DM + GS); commercial substrate based on peat (P); commercial substrate based on coconut fibre (CF); spent mushroom compost plus peat (1:1; v:v) (SM + P)

Nutrients	Gerbera			Carnation		
	DM + GS	P	SM + P	DM + GS	CF	SM + P
N (%)	2.06 a	2.88 b	2.13 a	2.98 b	4.17 a	3.38 a
P (%)	0.20 a	0.19 a	0.14 a	0.52 a	0.41 a	0.55 a
K (%)	2.01 b	0.93 a	2.15 b	4.55 b	3.68 a	4.57 b
Ca (%)	1.11 a	1.84 b	1.62 ab	1.57 a	1.28 a	2.14 b
Mg (%)	0.37 a	0.45 a	0.43 a	0.40 a	0.61 b	0.48 a
Fe (mg kg^{-1})	51.5 a	179.5 b	67.5 a	52 a	52 a	48 a
Mn (mg kg^{-1})	44.6 b	52.3 b	14.6 a	64 a	143 b	158 b
Cu (mg kg^{-1})	5.9 a	16.6 c	6.8 b	6 a	9 b	7 ab
Zn (mg kg^{-1})	12.9 b	36.6 c	3.9 a	41 a	30 b	42 a
B (mg kg^{-1})	30.1 b	11.8 a	11.9 a	18 a	18 a	16 a

In each row and for each species, values followed by the same letter are not statistically different according to the Tukey test at $p < 0.05$.

niums, Zn in gerbera, and P and some micronutrients in petunias are a bit lower. These possible nutritional deficiencies could be corrected by means of an adequate fertilisation management.

As a conclusion, the mixture of DM and GS may be composted very easily. The obtained product does not show any limiting features for its use as a medium for growing ornamental plants in container and can substitute conventional substrates, such as peat and coconut fibre. Its low content of EAW could be solved by means of mixtures with the latter or through a shorter and more frequent irrigation. The other disadvantage is its high variability in the contents of assimilable nutrients and the practical difficulty in performing specific analyses previous to their use. This could be overcome by means of an adequate fertilizer management, facilitating a correct nutrition of the plants. Future studies should be aimed at optimising the DM+GS proportion in mixtures with conventional substrates and at adapting irrigation and fertilisation to the characteristics of such mixtures.

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