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ORIGINAL PAPER

Sugarcane bagasses sewage sludge compost as a plant growth substrate and an option for waste management

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Abstract The possible utilization of sugarcane bagasses sewage sludge-based compost (BSC) as a substitution for widely using expensive peat in growth media for a horticultural crop, lettuce (*Lactuca sativa* L.), was evaluated. Five different treatments having different percentages of BSC and peat were established. Percentages of BSC addition to peat were 0, 10, 25, 40, and 60% v/v, respectively. Physical and chemical characteristics of different growth media were undertaken. Plant growth parameters and nutrient composition of lettuce plants were determined. In general, the proposed growing media created with peat and BSC had adequate physical and chemical properties and notable contents of plant nutrients, mainly P, K, Ca, and Mg. Moreover, BSC addition to peat enhanced the nutrient content in lettuce plants compared to plants grown in peat-only substrate. The highest increases of growth and yield parameters were obtained in the treatment having BSC and peat at 25 and 75% of the total volume, respectively. The shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight obtained from the media having BSC and peat at 25 and 75% were increased by 53.25, 43.32, 36.27, and 56.88%, respectively, compared to peat control. In addition, the mixture with the most BSC (60%) gave the greatest contents of K, Mg, Ca, Cu, Zn, Cr, and Pb. Trace element concentrations in plant tissues grown in media with BSC and peat were far below than the ranges considered phytotoxic for plants. These results indicate that these BSC-based media is a viable alternative to expensive peat for cultivation of lettuce.

Keywords Chemical and physical characterization · Peat substitution · Waste management · Nutrient uptake · Plant growing substrate · Plant nutrition

Abbreviations

BSC	Bagasses sewage sludge-based compost
OM	Organic matter
EC	Electrical conductivity

Introduction

Increased commercial interest has been directed toward developing complete or partial alternatives for peat utilized in traditional potting media not only for growing seedlings and propagation of plants but also for vegetable production. Both environmental and economical implications of peat usage have resulted in the development of new substrate to substitute peat worldwide (Abad et al. 2001). Public and private composting facilities have increased over the past decade around the world due to enhanced recycling efforts (Glenn 1999; Zhang et al. 2011). Composted organic wastes as growth substrates could be a feasible option, especially sewage sludge due to its high production (Teres et al. 1997).Composts used as components of substrates could modify the properties of peat, due to provision of nutrients, growth regulators, etc. (Bragg et al. 1993; Nappi and Barberis 1993). Moreover, sugarcane was introduced to the Okinawa and Kagoshima, Japan in the seventeenth century from China; then sugarcane became an important crop in the regional economy (Matsuoka 2006). The total

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sugarcane cultivating area in south western islands (Kagoshima and Okinawa) of Japan was about 3000 km^2, which produced approximately 1,200,000 t of sugarcane annually (Matsuoka 2006). Sugarcane waste (bagasses) is generating approximately at the rate of 300,000 t annually (Matsuoka 2006) and their utilization and disposal is a dominant challenge. In order to minimize the environmental impacts and to recycle these sugarcane residues, several alternatives have been proposed.

Sewage sludge production increases proportionally to the number of municipalities that put wastewater treatment plants into service. Recycling to soil is among the main sludge outlets, since amending with sludge meets requirements of efficient recycling of resources while providing organic matter for poor or degraded soils (Andrés et al. 2011). The composting of the bagasses with sewage sludge allows to treat them and also to obtain an end-product called compost, characterized for being a stable organic material containing humic-like substances. Composts may have physical and chemical properties similar to peat that make them suitable as peat substitutes (Chandra and Sathiavelu 2009; Sanchez-Monedero et al. 2004). However, several studies have reported that composts can also show features considered as limiting factors for their horticultural use, such as the presence of hazardous components (i.e., heavy metals) (Garcia-Gomez et al. 2002), poor physical properties (Ribeiro et al. 2000), phytotoxicity or an excess in salts or nutrients that originate media with high electrical conductivity (EC) (Sanchez-Monedero et al. 2004). Compost application could be also a promising alternative to alleviate the adverse effects caused by soil salinization. MSW compost with high organic matter content and low concentrations of inorganic and organic pollutants allow an improvement of physical, chemical, and biochemical characteristics and constitute low cost soil recovery (Lakhdar et al. 2009). However, the combination of peat with sewage sludge composts can reduce the potential poor properties of single materials, such as high salinity, heterogeneity, or high content of contaminants, as Raviv et al. (1986) indicated in a study using mixtures of peat with sewage sludge and other residual materials. Thus, the proportion of compost in the growing media is essential to reduce potential hazards, especially salinity. On the other hand, other researchers (Pinamonti et al. 1997; Eklind et al. 2001; Perez-Murcia et al. 2006) have reported that the presence of composts in the growing media tends to reduce the concentration of heavy metals in plants, due to the higher pH values that usually result. Composted sewage sludge usually contains high levels of organic matter, and is rich with N, P, K, and micronutrients that are essential for plant growth. Organic matter contributes to plant growth through its effect on the physical, chemical, and biological properties of the soil (Benito et al. 2005). The objective of this study was to investigate the influence of the utilization of bagasses sewage sludge-based compost (BSC) media on the growth and nutrient dynamics of popular leafy vegetable lettuce (*Lactuca sativa* L.).

Materials and methods

Preparation of growth media

A mixture of sewage sludge and bagasses were used to produce BSC. Bagasses were ground into fragments between 2 and 15 cm before using in the compost mix. Turned windrow aerated-pile method was applied for BSC, using triangular windrows of 5.5 m width and 2.5 m height. Physical and chemical properties of BSC are given in Table 1. Five different growing media were tested. Peat, which is a commercial growing media, is used as the control. Five treatments were established, based on the addition of increasing quantities of BSC to peat (0, 10, 25, 40, 60% v/v). Ratios of each component in each substrate are shown in Table 2.

Experiment setup

A green house pot experiment was conducted to study the influence of different substrates containing different ratios of BSC and peat on lettuce (*Lectuca sativa* L.) growth. Container volume was 1.5 l. Table 2 shows the volumetric

Table 1 Physical and chemical properties of BSC

Parameter	BSC
Bulk density (g cm^{-3})	0.31 ± 0.05
pH	7.15 ± 0.21
EC (dS m^{-1})	2.06 ± 0.28
OM (g kg^{-1})	561.00 ± 4.32
N (g kg^{-1})	16.41 ± 1.03
C/N	20.23 ± 2.16
P (g kg^{-1})	28.12 ± 1.12
K (g kg^{-1})	4.21 ± 0.61
Mg (g kg^{-1})	0.96 ± 0.35
Ca (g kg^{-1})	1.12 ± 0.13
Cu (mg kg^{-1})	116.00 ± 2.21
Zn (mg kg^{-1})	232.00 ± 5.32
Cd (mg kg^{-1})	ND
Cr (mg kg^{-1})	15.60 ± 1.26
Mn (mg kg^{-1})	88.21 ± 1.33
Pb (mg kg^{-1})	46.24 ± 1.06

Values are mean ± standard deviation ($n = 5$)

BSC bagasses-sugarcane-based compost, *EC* electrical conductivity, *OM* organic matter, *ND* not detected

Table 2 Composition of the growing media

Treatments	Formulation
T1	100% Peat (commercial substrate)
T2	10% BSC + 90% peat
T3	25% BSC + 75% peat
T4	40% BSC + 60% peat
T5	60% BSC + 40% peat

BSC bagasses sewage sludge-based compost

formulations of different container substrates utilized in this study. The acidic pH of the peat (4.34) was adjusted to 5.50 by adding lime. T1 was also enriched with 2 g of slow release fertilizer N:P:K: 15–15–15 to supply minimum requirement of fertilizer. Experimental design of the pot experiment was a completely randomized design (CRD) with 5 treatments and 5 replicates. Prepared air-dried substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without unnecessary compaction. All pots were arranged in a greenhouse and saturated and kept for 48 h to attain their respective field capacities. Two-week-old lettuce plants obtained from a prepared nursery were planted in each pot. Two plants were initially planted and thinned out to one plant in each pot. 200 ml water was added to each pot once in 2 days. Experiments were terminated after 7 weeks of planting. Plant shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight were determined. Plants were oven-dried at 70°C for 48 h to determine the dry weight.

Plant and growth media analysis

Physical properties of each substrate materials were determined using procedures described by Spomer (1990) and Pill et al. (1995). Each moistened pre-plant substrate was placed in 12.5 cm diameter standard plastic pots. Each pot was irrigated for 2 weeks in the same manner. After 2 weeks of irrigation, containers drainage holes were sealed with duct tape. Water was then added to each substrate until saturated. After determining the weight of saturated substrate, the drainage holes were unsealed and substrates were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then substrates were oven-dried at 65°C for 48 h and the amounts of water retained by substrates after draining were determined. The weight of water needed to saturate each substrate was divided by the medium bulk volume to determine total pore space percentage. Substrate bulk density was determined by dividing oven-dried weight of each substrate by substrate bulk volume. Coarseness index (CI), expressed as weight percentage of particles with $\varnothing > 1$ mm (Richards et al. 1986) was determined. All measurements were carried out 5 times.

The pH was measured in water extracts of all substrate samples using a glass electrode (sample:distilled water ratio of 1:5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (sample:distilled water ratio of 1:5). Carbon (C) and nitrogen (N) contents in substrate samples were determined using CN analyzer (Micro coder JM 10; G-Science Laboratory, Tokyo, Japan). Plant samples and substrates were mineralized by microwave acid-digestion (USEPA 1996) and the concentrations of K, Ca, Mg, Mn, Cu, Zn, Pb, Cd, and Cr were determined by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Total P of substrate samples was determined using a spectrophotometer. Organic matter of the substrate samples was determined by loss on ignition at 430°C for 24 h (Navarro et al. 1993).

Statistical analysis

Obtained data were subjected to analysis of variance to determine the treatment effects. Duncan's multiple comparison range test was used to determine significant differences between the treatments using SAS package (SAS Institute 1990).

Results and discussion

Properties of the growing media

Physical properties of the growing media

Table 3 shows physical properties of different growth substrates utilized in the experiment. It is evident that the bulk density and particle density of the substrates increased significantly ($P < 0.05$) with the increasing amount of BSC in the growing mixture. Bulk density values of T2, T3, T4, and T5 were increased by 5.55, 22.22, 33.33, and 55.55%, respectively, compared to peat control (T1).Our results were supported by some researchers who reported that addition of compost increased the substrate bulk density (Grigatti et al. 2004). Sewage sludge compost addition improved soil characteristics such soil porosity and bulk density (Song and Lee 2010). Moreover, in all the media, bulk density values were within the limits established for an ideal substrate (<0.4 g cm^{-3}) according to Abad et al. (2005). Particle density of all substrates was within the ideal limit (1.4–2.0). Air spaces of T1 and T2 were not within the established ideal limits but T3, T4, and T5 were within the established ideal limits. Air spaces of the substrates were increased with the increasing amount of BSC in the substrate mixture. This may be probably due to the greater proportion of particles with size >1 mm, because of BSC addition. De Boodt and Verdonck (1972) revealed

Table 3 Physical properties of the growing media

Treatments	Bulk density ($g\ cm^{-3}$)	Particle density ($g\ cm^{-3}$)	Air space (%)	Total porosity (%)	Water holding capacity ($mL\ L^{-1}$)	CI (%)
T1	0.18 ± 0.02c	1.70 ± 0.11d	17.70 ± 0.38e	89.41 ± 1.66a	717.10 ± 4.20a	28.33 ± 1.12e
T2	0.19 ± 0.04bc	1.76 ± 0.20c	19.01 ± 0.42d	89.20 ± 1.59a	701.90 ± 5.12b	31.41 ± 0.96d
T3	0.22 ± 0.03b	1.83 ± 0.16b	23.66 ± 0.41c	87.97 ± 1.20b	643.10 ± 6.16c	38.20 ± 0.85c
T4	0.24 ± 0.04b	1.86 ± 0.09ab	24.98 ± 0.29b	87.09 ± 1.36b	621.10 ± 4.68d	42.51 ± 0.72b
T5	0.28 ± 0.06a	1.90 ± 0.12a	25.44 ± 0.47a	85.26 ± 1.75c	598.20 ± 6.59e	51.82 ± 0.61a
ID	<0.40	1.4–2.0	20–30	>85	600–1000	30–45

Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test ($P = 0.05$). Values are mean ± standard deviation ($n = 5$)

CI coarseness index, *ID* ideal substrate (Abad et al. 2001)

that low percentages of air space in peat-based substrates may cause problems for plant growth. All substrates utilized in this study gave established ideal porosity values but porosity was decreasing with the increasing amount of BSC. The decreased of porosity with compost addition was also reported by several authors (Ingelmo et al. 1998; Guerrero et al. 2002) for peat substrates. Water-holding capacities of all substrates were within the ideal limit except T5 and decreased significantly with the addition of BSC. Water-holding capacity of T2, T3, T4, and T5 were decreased by 2.12, 10.32, 13.39, and 16.58%, respectively, compared to peat control. Abad et al. (2005) reported in a study on the physical properties of different coconut coir dust samples that water-holding capacity diminished proportionally with increasing coarseness index. Coarseness index (CI) of the growth substrate was increased with the increasing percentage of BSC as a media component compared to peat control. Except T5 substrate, the CI of all other substrates was within the established ideal range. There is no single ideal growth medium for plant production (Bugbee and Frink 1996). Although BSC addition affected some measured parameters, physical properties of the substrates were generally within the recommended ranges for horticultural crops (Poole et al. 1981; Bunt 1988; Rynk et al. 1992).

Chemical properties of the growing media

BSC addition significantly affected the media pH (Table 4). All the substrates, showed pH values within the established ideal range (5.3–6.5) suggested by different authors (Noguera et al. 2003; Sanchez-Monedero et al. 2004) except T5. Although there is no single, ideal growth medium for nursery-produced horticultural crops (Raviv et al. 1986; Bugbee and Frink 1996; Poole et al. 1981), most greenhouse-grown species display better growth at slight acid pH values (5.2–7.0); mixtures with BSC and peat approach these values. The EC values of the growth substrates were strongly affected by the addition of BSC. EC values exceeded the limit for an ideal substrate ($<0.5\ dS\ m^{-1}$) suggested by De Boodt and Verdonck (1972) in all growth media except T1 and T2. The EC of BSC compost used in our study did not exceed the limit of $3.5\ dS\ m^{-1}$ recommended by Noguera et al. (2003). Moreover, high EC of BSC can be reduced by mixing with peat. Abad et al. (2001) reported that a value for total organic matter above $800\ g\ kg^{-1}$ should be adequate for potting media. The organic matter content in all media was lower than the minimum recommended value. The N content in all substrates ranged between 7.52 and $13.62\ g\ kg^{-1}$. The N content was increased with the increasing amount of BSC in the substrate mixture. Sewage sludge compost incorporation to the soil increased properties such as moisture, organic matter, N content, and respiration (Song and Lee 2010). The C/N ratio varied between 25.71 and 54.78. The ideal established C/N ratio for a potting media should be 20–40 (Abad et al. 1993). C/N ratio of T3, T4, and T5 were within the established ideal range. It is evident that BSC addition declined the C/N ratio compared to peat control. Wilson et al. (2001) found that an increased proportion of compost in crop substrates prompted a decline in the C/N ratio compared to peat, although this will depend on the proportion of each ingredient in the mixture. P concentration in BSC-based media were significantly ($P < 0.05$) higher than that of peat control (T1). This is due to high P concentration in the BSC (Table 1). The presence of BSC in the media mixture increased the concentrations of K, Mg, and Ca. This is also due to the increased amount of K, Mg, and Ca in the BSC (Table 1). Concentrations of Cu, Zn, Cr, Mn, and Pb in the BSC-based media were increased significantly with increasing amount of BSC compared to peat control but were below the stated limits given by Abad et al. (1993). Cd was not detected in any media. It is evident that BSC addition as a potting media component to substitute peat increased the nutrient availability in the growing media. The contents of Cd, Cr, Cu, Pb, and Zn in BSC and BSC–peat-based media were low and did not exceed the limits

Table 4 Chemical properties of the growing media

	T1	T2	T3	T4	T5	Optimal ranges[a] and limit values[b]
pH	5.50 ± 0.21e	6.12 ± 0.18d	6.27 ± 0.12c	6.42 ± 0.20b	6.67 ± 0.13a	5.3–6.5[a]
EC (dS m^{-1})	0.28 ± 0.06e	0.48 ± 0.10d	0.69 ± 0.11c	0.87 ± 0.09b	1.12 ± 0.11a	<0.5[a]
OM (g kg^{-1})	704.00 ± 4.22a	687.12 ± 3.21b	646.26 ± 3.87c	622.04 ± 3.08d	582.32 ± 2.79e	>800[a]
C/N	54.78 ± 1.12a	45.56 ± 0.76b	38.17 ± 0.65c	30.94 ± 0.84d	25.71 ± 0.71e	20–40[a]
C	412.02 ± 2.13a	401.83 ± 3.21b	380.25 ± 3.08c	364.20 ± 2.76d	350.30 ± 1.98e	–
N (g kg^{-1})	7.52 ± 0.66e	8.82 ± 0.70d	9.96 ± 0.35c	11.77 ± 0.78b	13.62 ± 0.54a	–
P (g kg^{-1})	0.50 ± 0.04e	4.81 ± 0.06d	8.98 ± 0.08c	14.26 ± 0.04b	19.40 ± 0.03a	
K (g kg^{-1})	0.98 ± 0.12e	1.42 ± 0.23d	1.96 ± 0.15c	2.58 ± 0.11b	3.21 ± 0.21a	–
Mg (g kg^{-1})	0.44 ± 0.04d	0.51 ± 0.06 cd	0.60 ± 0.02bc	0.70 ± 0.05ab	0.79 ± 0.03a	–
Ca (g kg^{-1})	0.51 ± 0.12d	0.58 ± 0.15d	0.69 ± 0.09c	0.81 ± 0.11b	0.91 ± 0.16a	–
Cu (mg kg^{-1})	14.32 ± 0.77e	26.65 ± 1.10d	47.40 ± 1.12c	59.66 ± 0.96b	79.62 ± 1.70a	500[b]
Zn (mg kg^{-1})	20.32 ± 0.88e	49.32 ± 0.76d	87.37 ± 1.21c	128.45 ± 1.35b	162.92 ± 1.50a	1500[b]
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	5[b]
Cr (mg kg^{-1})	1.16 ± 0.34e	3.32 ± 0.28d	5.98 ± 0.17c	8.56 ± 0.26b	11.12 ± 0.37a	200[b]
Mn (mg kg^{-1})	19.41 ± 0.56e	29.90 ± 0.67d	39.56 ± 0.42c	53.18 ± 0.38b	66.01 ± 0.87a	–
Pb (mg kg^{-1})	1.26 ± 0.12e	6.36 ± 0.23d	14.79 ± 0.29c	22.30 ± 0.31b	31.68 ± 0.42a	1000[b]

[a] Optimal ranges and [b] limit values for heavy metals in raw materials are shown (values are mean ± standard deviation ($n = 5$)). For each variable, values followed by the same letter do not differ significantly ($P < 0.05$)

EC electrical conductivity, [a,b] *OM* organic matter (Abad et al. 1993)

for land application of sewage sludge recommended by the United States Environmental Protection Agency (Table 1, 4). These limits, in terms of mg kg^{-1} of dry weight, are as follows: Cd, 39; Cr, 1200; Cu, 1500; Pb, 300; Zn, 2800 (USEPA 1999). Therefore, BSC-based media used in this research did not pose a regulated heavy metals toxicity problem. The horticultural compost would be assigned to category "A" following the compost standards in Canada, which stipulated values lower than (mg kg^{-1} of air-dried mass): Cd, 3; Cr, 210; Cu, 100; Pb, 150; Zn, 500 (http://www.compost.org/standard.html).

Influence of BSC addition on the growth parameters of lettuce

The influence of BSC in the growth media mixture on the growth of lettuce plant is given in Table 5. Significant increases ($P < 0.05$) in dry and fresh weight of shoot and root parts of lettuce grown in BSC-based media were observed compared to lettuce grown in peat control. Our results were supported by similar yield increments results observed by several researchers after addition of compost as a growth media component for crop cultivation (Pinamonti et al. 1997; Atiyeh et al. 2001; Garcia-Gomez et al. 2002; Kumar et al. 2009), which were mainly due to the great contribution of nutrients, especially N and P, by composts. Sanchez-Monedero et al. (1997), in experiments using substrates obtained by mixing composts from different origins with peat to grow horticultural plants (broccoli, tomato, and onion), found that compost could be used at up to 66.7% by volume with no negative effects on plant growth. The highest increases of yield parameters were obtained in T3, where BSC and peat were present as 25 and 75% of the total volume, respectively. The shoot

Table 5 Effects of different substrates on the growth of lettuce

Treatments	Fresh weight (g)	Dry weight (g)	Root fresh weight (g)	Root dry weight (g)
T1	90.86 ± 0.48e	3.37 ± 0.34e	11.36 ± 0.34e	1.09 ± 0.12e
T2	95.78 ± 0.53d	3.56 ± 0.58d	11.77 ± 0.41d	1.34 ± 0.19d
T3	139.25 ± 0.76a	4.83 ± 0.64a	15.48 ± 0.74a	1.71 ± 0.23a
T4	118.96 ± 0.84b	4.34 ± 0.51b	13.87 ± 0.56b	1.56 ± 0.27b
T5	107.64 ± 0.71c	3.78 ± 0.60c	12.23 ± 0.41c	1.42 ± 0.18c

Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test ($P = 0.05$). Values are mean ± standard deviation ($n = 5$)

fresh weight, shoot dry weight, root fresh weight, and root dry weight obtained from the T3 were increased by 53.25, 43.32, 36.27, and 56.88%, respectively, compared to peat control. The second highest yield parameters were given by T4, which showed increased shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight by 30.93, 28.78, 22.10, and 43.12%, respectively, compared to peat control. This could be due to improved physical and chemical properties with substitution of peat by BSC. The increases in biomass production with the use of sewage sludge-based composts as substrate components have been also reported by other authors (Garcia-Gomez et al. 2002; Perez-Murcia et al. 2006); this could be due to the fertilizing capacity of this compost. In addition, the leaf biomass and tree physiological parameters such as the chlorophyll contents and photosynthesis rates increased after the sewage sludge compost treatments (Song and Lee 2010). The addition of 60% of BSC in T5 treatment also showed increased shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight by 18.47, 12.17, 7.66, and 30.28%, respectively, compared with the peat control. On the other hand, the inclusion of all BSC rates as substrate components in the growth substrates did not pose any constraint for plant growth compared to T1. In summary, lettuce grew better in the assayed BSC media than in the control substrate. These results seem to indicate that these BSC-based media may be a viable alternative to peat for containerized production of lettuce.

Nutrition composition of lettuce plants

The addition of BSC as a component in the growth substrates on the element concentrations in plant tissues is given in Table 6. It is evident that N, K, Mg, and Ca concentrations of the BSC-based media were increased compared to peat control. N content of all substrates were above the deficiency level of 15 g kg^{-1} according to Chapman (1966). P concentration of plant tissues obtained from BSC-based media was significantly higher compared to peat control. Furthermore, increases of P concentrations in lettuce tissues in response to N supply have also been reported in literature (Marschner 1995). In our study, the BSC-based substrate had a notable amount of N (Table 4), which could cause higher P in plant tissues. Shoot K, Ca, and Mg contents were all above the deficiency limit of 7–15 g kg^{-1} (Chapman 1966), 1.4 g kg^{-1} (Loneragan and Snowball 1969), and 0.6 g kg^{-1} (Chapman 1966), respectively. Generally, N supply will increase the Ca uptake of plant tissues (Marschner 1995). These increased element concentrations could be attributed to the higher concentration of these elements observed in the BSC. Positive effects on plant nutrition derived from using composted sewage sludge in growing media have been reported in literature (Pinamonti et al. 1997; Raviv et al. 1986). Therefore, a combination of peat with composts can minimize the negative properties of a single material, thus obtaining sound and cheap substrates (Raviv et al. 1986; Bures 1997). The presence of high levels of micronutrients or potentially toxic elements in sewage sludge would be a serious constraint for propagating media preparation. Heavy metal contents in all organs of two varieties of tomato under different treatments of sewage sludge compost applications were below normal levels and toxicity level. Also they are more than accepted as safe for human consumption (Begum 2011). In general, none of the trace elements studied reached phytotoxic levels in plants (the

Table 6 Element concentrations in lettuce plant shoots

Elements	T1	T2	T3	T4	T5	Normal range	Phytotoxic range
N (g kg^{-1})	20.78 ± 0.62c	24.04 ± 0.55b	26.23 ± 0.91a	25.81 ± 0.67a	25.32 ± 0.68b		
P (g kg^{-1})	0.71 ± 0.40d	1.06 ± 0.58c	1.64 ± 0.50a	1.70 ± 0.43a	1.59 ± 0.34b		
K (g kg^{-1})	14.14 ± 0.18d	16.33 ± 0.88c	18.25 ± 0.67b	18.61 ± 0.96b	19.60 ± 0.74a		
Mg (g kg^{-1})	4.39 ± 0.42d	5.13 ± 0.56c	5.45 ± 0.57b	5.42 ± 0.51b	5.98 ± 0.49a		
Ca (g kg^{-1})	10.85 ± 0.36d	11.36 ± 0.95d	11.98 ± 0.51c	12.49 ± 0.34b	14.51 ± 0.89a		
Cu (mg kg^{-1})	3.72 ± 0.40c	3.82 ± 0.65c	3.96 ± 0.44ab	3.87 ± 0.34b	4.01 ± 0.49a	3–20	25–40
Mn (mg kg^{-1})	116.21 ± 2.41a	96.23 ± 1.28b	83.84 ± 2.05c	84.26 ± 2.44c	83.89 ± 2.48c	15–150	400–2000[a]
Zn (mg kg^{-1})	22.81 ± 1.20c	21.12 ± 0.65d	21.77 ± 0.60c	23.18 ± 0.66b	26.12 ± 0.58a	15–150	500–1500
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	0.1–1	5–700
Cr (mg kg^{-1})	0.41 ± 0.11b	0.45 ± 0.08b	0.46 ± 0.13b	0.48 ± 0.10b	0.58 ± 0.15a	0.02–14[b]	–
Pb (mg kg^{-1})	0.47 ± 0.03c	0.48 ± 0.06c	0.52 ± 0.05b	0.54 ± 0.06b	0.65 ± 0.04a	2–5	–

For each row values followed by the same letter do not differ significantly according to Duncan multiple range test ($P < 0.05$). Values are mean ± standard deviation ($n = 5$)

[a] Critical toxicity concentration (Romheld and Marschner 1991): from [b] Adriano (2001)

growth was not affected). In general, Cu, Mn, Zn, Cd, Cr, and Pb concentrations in plants were far lower than the phytotoxic ranges (Romheld and Marschner 1991) and in some cases even lower than the ranges considered normal for plants (Adriano 2001). Heavy metal accumulation in the soil after the treatments of sewage sludge compost was lower than the Ecological Soil Screening Levels (Eco-SSLs) for plants set by the US Environmental Protection Agency (EPA). Further, heavy metal accumulation in the leaves was insignificant compared with that of the control (Song and Lee 2010). Highest Mn content was reported in T1. This fact could be due to a decrease in the availability of Mn with the increase in the pH of the media after the addition of the composts (Perez-Murcia et al. 2006). For Mn, a concentration decrease derived from the composts application has been reported by other authors (Gallardo-Lara and Nogales 1987; Murillo et al. 1995; Madejon et al. 2006).

Conclusions

It can be concluded that, in general, the substrates elaborated with BSC showed suitable physical and chemical properties, absence of phytotoxicity, and important nutrient contents. However, BSC-added substrates also showed pH and EC values higher than pure peat, which can constitute the main limiting factors for their use as growing media. On the other hand, these media did not induce any reduction in plant growth compared to peat. Moreover, BSC-based media can be considered as valuable partial peat substitutes for lettuce due to their efficient physical and chemical characteristics. The highest increases of yield parameters were obtained in the substrate, where BSC and peat were present as 25 and 75% of the total volume, respectively. The shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight obtained from the T3 were increased by 53.25, 43.32, 36.27, and 56.88%, respectively, compared to peat control. Moreover, addition of BSC as a media component increased the nutrient concentrations (N, P, K, Mg, Ca, Cu, Mn, Zn, and Pb) in the lettuce plant and the trace element levels in the tissues were far below than the phytotoxic levels. Recycling BSC as fertilizer will generate economical profits. Therefore, the use of BSC as a soil conditioner in landfills would be an efficient and cost-effective method to restore the fertility of reclaimed soil and an environment-friendly solution for disposal problems.

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