Journal of Hazardous Materials 174 (2010) 700–706

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Sewage sludge sugarcane trash based compost and synthetic aggregates as peat substitutes in containerized media for crop production

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ARTICLE INFO

Article history:
Received 9 June 2009
Received in revised form
18 September 2009
Accepted 18 September 2009
Available online 25 September 2009

Keywords:
Composts
Growing media
Peat
Sewage sludge
Sugarcane

ABSTRACT

Effect of partial substitution of peat in growth media by sewage sludge sugarcane trash based compost (SSC) and synthetic aggregates (SA) on the physical and chemical characteristics of the growth media and on the growth and nutrition of lettuce (*Lactuca sativa* L.) grown in the substituted media was investigated under this study. SSC was produced from sugarcane trash and sewage sludge. Unconventional SA were produced by low productive acidic red soil with paper waste and starch waste. The treatments assayed were: SSC (40%) + Peat (60%), SA (40%) + Peat (60%), SSC (60%) + SA (40%), SSC (40%) + SA (20%) + Peat (40%) and SSC (40%) + SA (40%) + Peat (20%). Peat only was used as the control. The physical and chemical properties of all growing media were analyzed. SSC–SA based substrates showed adequate physical and chemical properties compared to peat for their use as growing media in horticulture. In relation to the plant growth in peat control, plants grown in the SSC–SA based substrates reached better growth and nutrition. The concentration of trace elements in plant tissues was far lower than the ranges considered phytotoxic for plants. Utilization of SSC and SA can be considered as an alternative media component to substitute the widely using expensive peat in horticulture.

1. Introduction

In recent years there has been increasing environmental and ecological concerns against use of peat as a growth substrate because its harvest is destroying endangered wetland ecosystems worldwide [1,2]. Moreover, increasing demand and rising costs for peat as a growing substrate in horticulture have led to search for high quality and low cost substrates as an alternative. A number of studies have shown that organic residues such as urban solid wastes, sewage sludge, paper waste, pruning waste, spent mushroom and even green wastes, after proper composting, can be used with very good results as growth media instead of peat [3–7]. The increasing interest in waste recycling is another cause to advocate the recycling and use of organic wastes and composts as soil or potting amendments; it could be one of the most attractive methods of solving the problem of waste disposal. The combination of peat and compost in growing media is synergistic; peat often enhances aeration and water retention and compost improves the fertilizing capacity of a substrate [3]. In addition, organic by-products and composts tend to have porosity and aeration properties comparable to those bark and peat and as such are ideal substitutes in propagating media [8].

About 2.44×10^8 and $4.14 \times 10^8\,m^3$ of sewage sludge were reportedly produced in Japan in 1990 and 2004, respectively [9,10], corresponding to an increase of 170% in sewage sludge over just 14 years. Sludge processing generally consists of thickening, dewatering and several different alternative main treatments, such as anaerobic digestion, composting, incineration and melting [11]. Composting is a stabilization process of aerobic decomposition and leads to the development of microbial populations which causes numerous physico-chemical changes in the waste mixture [12]. Composting can reduce the mixture volume by 40 – 50%, effectively destroy the pathogens by the metabolic heat generated by the thermophilic phase, degraded a big number of hazardous organic pollutants and provide a final product that can be used as a soil amendment or fertilizer [12]. Land application of composted sewage sludge represents one of the most cost effective methods for treatment and final disposal of sewage sludge, because the high levels of valuable components (N, P, K, organic matter and other necessary nutrients for plant growth) in stable sludge can be recycled and the properties of soil can be improved [13–16].

Abbreviations: SSC, sewage sludge sugarcane trash based compost; SA, synthetic aggregates; OM, organic matter; EC, electrical conductivity.

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doi:10.1016/j.jhazmat.2009.09.107

The use of sewage sludge mixed with different organic waste materials such as rice straw, green waste is now usual in composting experiments [17,18]. Sugarcane trash is generating approximately at the rate of 300000 tons annually in southern Japan [19] and it has been suggested as a potential soil conditioner due to having efficient plant nutritive values. In order to minimize the environmental impact and to recycle these sugarcane residues, several alternatives have been proposed, composting being a feasible method from both technical and economical points of view. Moreover, mixing of sugarcane trash with sewage sludge in compost mixture not only enhances the nutritive value of the by-product but, at the same time also suppresses the toxicity by metals through supplying a considerable amount of organic matter [18]. Sewage sludge and sugarcane trash were used to produce sewage sludge sugarcane trash based compost (SSC).

Composts may have physical, physico-chemical and chemical properties similar to peat that make them suitable as peat substitutes [20]. However, several studies [8,11,13,15,16,20–22] have reported that sewage sludge composts can also show features considered as limiting factors for their horticultural use, such as the presence of hazardous components (i.e. heavy metals), poor physical properties, phytotoxicity or an excess of salts or nutrients that originate media with high electrical conductivity. However, the combination of peat with composts can reduce the potential poor properties of single materials according to Raviv et al. [23] 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, specially salinity. Perez-Murcia et al. [24] reported that addition of compost to peat increased plant nutrient and heavy metal concentrations of plants and substrates. On the other hand, other researchers [25–27] have reported that the presence of compost in the growing media tends to reduce concentrations of heavy metals in plants, due to the higher pH values that usually result.

Widely spread red soil ("Kunigami Mahji") in sub-tropical Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical [28] and chemical properties [29]. This prompted for the development of an effective method of converting under utilized red soil into fertile, arable synthetic aggregates (SA) by incorporating paper waste and starch waste in order to improve its physical and chemical properties. Several of our previous studies were conducted using SA developed from different waste materials. SA formed from coal fly ash, paper waste and starch waste addition to the low productive problematic soil as a soil ameliorant improved the physical and chemical properties of the low productive soil and subsequently increased the crop production [30,31]. A potting medium developed from coal fly ash based SA and oil palm waste 1:10 gave improved ornamental plant production [32]. SA developed from acidic soil, coal fly ash and starch waste as a crop growth medium increased the growth and yield of soybean (*Glycine max*) and Komatsuna (*Brassica rapa*) [33]. Addition of 30–40% of SA formed by acidic red soil and paper waste to problematic grey soil in Okinawa, Japan improved the properties of the grey soil and subsequently improved the ornamental plant production [34]. Moreover, SA developed by paper waste and acidic soil can be used as a partial substitution for peat in the growth medium for cultivation of ornamental *Tagetes patula* [35]. In this present study SA developed from red soil, paper waste and starch waste along with SSC were used as a growth medium for lettuce cultivation. The main objective of the present work was to ascertain the suitability of these SSC–SA based media as peat substitutions for lettuce production by studying their effects on vegetative and nutritional aspects to determine if there is any limitation to their use.

Table 1
Physical and chemical properties of growing media components, SSC and SA.

Parameter	SSC	SA
Bulk density (g cm^{-3})	0.31	0.56
pH	7.15	5.50
EC (dSm^{-1})	2.06	0.51
OM (g kg^{-1})	561	142
N (g kg^{-1})	16.41	0.40
C/N	20.23	213.5
P (g kg^{-1})	28.12	0.08
K (g kg^{-1})	4.21	0.31
Mg (g kg^{-1})	0.96	0.62
Ca (g kg^{-1})	1.12	0.91
Cu (mg kg^{-1})	116	13.20
Zn (mg kg^{-1})	232.27	26.48
Cd (mg kg^{-1})	ND	ND
Cr (mg kg^{-1})	15.6	1.81
Mn (mg kg^{-1})	88.21	20.48
Pb (mg kg^{-1})	46.24	4.48

SSC, sewage sludge sugarcane trash based compost; SA, synthetic aggregates; EC, electrical conductivity; ND, not detected. ($n = 5$).

2. Materials and methods

2.1. Growing media preparation

SSC was produced by composting a mixture of sewage sludge and sugarcane trash. Before composting, sugarcane trash was ground to fragments between 2 and 15 cm. Turned windrow aerated-pile method was applied for SSC, using triangular windrows of 5.5 m width and 2.5 m height. SA were produced by combining red soil and paper waste using an Eirich mixer (R-02M/C27121) with starch waste as a binder. One thousand grams of red soil and 100 g of waste paper was mixed in the Eirich mixer by adding 225 mL of starch paste. Physical and chemical properties of SSC and SA are given in Table 1. Six growing media were tested. Peat, which is a commercial growing media used as the control. The treatments assayed were: SSC (40%) + Peat (60%), SA (40%) + Peat (60%), SSC (60%) + SA (40%), SSC (40%) + SA (20%) + Peat (40%) and SSC (40%) + SA (40%) + Peat (20%). Ratios of each component in each substrate are shown in Table 2.

2.2. Physical and chemical properties of the growing media

Physical properties of each growth substrates (Table 2) were determined using procedures described by Spomer [36] and Pill et al. [37]. 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

Table 2
Composition of the growing media.

Treatments	Formulation
T1	100% Peat (commercial substrate)
T2	40% SSC + 60% peat
T3	40% SA + 60% peat
T4	60% SSC + 40% SA
T5	40% SSC + 20% SA + 40% peat
T6	40% SSC + 40% SA + 20% peat

SSC, sewage sludge sugarcane trash based compost; SA, synthetic aggregates.

Table 3
Physical properties of the growing media.

Treatments	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Air space (%)	Total porosity (%)	Total water holding capacity (mL L^{-1})	CI (%)
T1	0.18d	1.70d	17.71c	89.41a	717a	28d
T2	0.23c	1.76d	22.13b	86.93b	648b	39c
T3	0.33b	2.02b	23.56a	83.66c	601c	48b
T4	0.38a	2.15a	21.73b	82.33c	606c	69a
T5	0.31b	1.94c	23.02ab	84.02c	610c	45b
T6	0.38a	2.12a	21.98b	82.08c	601c	65a
ID	<0.40	1.4–2.0	20–30	>85	550–800	30–45

CI, coarseness index; ID, ideal substrate according to Bustamante et al. [4], Abad et al. [45] and Noguera et al. [53]. Values are means ($n = 5$). Within each column values followed by different letters are significantly different based on Duncan's test ($p < 0.05$).

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, expressed as weight percentage of particles with ∅ > 1 mm was determined according to Richards et al. [38]. All measurements were carried out five 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 by using CN analyzer (Micro coder JM 10; G-Science Laboratory, Tokyo, Japan). Plant samples and substrates were mineralized by microwave acid-digestion [39] and the total concentrations of K, Ca, Mg, Mn, Cu, Zn, Pb, Cd and Cr were determined by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Extractable metals of the growth media were analyzed by atomic absorption using the method described by Lindsay and Norvell [40]. Exchangeable K, Mg and Ca of growth media were determined using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan) after extracting with 1N CH_3COONH_4 (at pH 7.0). Total P of growth substrate samples was determined by using spectrophotometer [41]. Available P of growth media was determined based on extraction using $NaHCO_3$ [42]. Organic matter (OM) of the substrate samples was determined by loss on ignition at 430 °C for 24 h [43].

2.3. Pot experiment

A greenhouse pot experiment was conducted to study the influence of different substrates containing different ratios of SSC, SA and peat on lettuce (*Lactuca sativa* L.) plant growth. Container volume was 1.5 L. Table 2 shows the volumetric formulations of different container substrates utilized in this study. The acidic pH of the peat (4.34) were adjusted to 5.50 by adding lime. T1 and T3 were enriched with 2 g of slow release fertilizer N:P:K = 15:15:15 to supply the minimum fertilizer requirements. Experimental design of the pot experiment was a completely randomized design (CRD) with six treatments and five 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 weeks 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. Temperature ranged from 20 to 31 °C during the growth season. 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 for 48 h to determine the dry weight. Plant materials were ground and passed through 2 mm mesh sieve and digested with nitric acid for the mineral element analysis by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

2.4. 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 means using SAS package [44].

3. Results and discussion

3.1. Physical and chemical properties of the growing media

Physical properties of growth substrates are given in Table 3. Bulk density of the media increased significantly with the presence of SSC and SA in the growing mixture. Similar results were reported by a previous study conducted using compost based media for bedding plants by Grigatti et al. [2]. In all the media, bulk density values were within the limits (<0.4 g cm^{-3}) established for an ideal substrate [45]. Initial particle density of peat (1.70 g cm^{-3}) was increased in all treatments with the addition of SA and SSC. Particle density of T1, T2 and T5 were within the ideal limit (1.4–2.0 g cm^{-3}) according to Abad et al. [45]. Particle densities increased with the addition of sludge, as found in previous studies [46,47]. T3, T4 and T6 were not within the ideal limit and it exceeded the ideal limit. This may be mainly due to the addition of SA. Potting media containing different ratios of synthetic soil-paper waste aggregates and peat gave increased particle density compared to peat control. This may be due to addition of synthetic aggregates having higher particle density [35]. Air spaces of all substrates were within the established ideal limits except for peat (T1). Moreover, air spaces of SSC and SA based media were significantly higher than the peat. This may be probably due to the great proportion of particles with size >1 mm, because of SSC and SA addition. Low percentages of air space in peat based substrates may cause problems for plant growth [48]. T1 and T2 gave established ideal porosity values. Water holding capacity of all substrates were within the ideal limit but decreased significantly with the addition of SSC and SA. Similar results were found by a previous study conducted using compost based media for bedding plants by Grigatti et al. [2]. In a study conducted on the physical properties of different coconut coir dust samples reported that water holding capacity diminished proportionally with increasing coarseness index [49]. Coarseness index of the growth media was increased with addition of SSC and SA as media component compared with peat only substrate. Although there is no single ideal growth medium for plant production [50], physical properties of the substrates formed by substitution of peat with SSC and SA were generally within the recommended ranges for plant production [51,52].

Chemical properties of the media are given in Table 4. In general, all the substrates, including peat, showed pH values within the established optimal range (5.2–6.5) suggested by different authors

Table 4
Chemical properties of the growing media.

	T1	T2	T3	T4	T5	T6	Optimal ranges^x and limit values^y
pH	5.50d	6.15c	5.50d	6.40a	6.12c	6.28b	5.3–6.5^x
EC (dSm^{-1})	0.28d	0.72b	0.39c	1.02a	0.76b	0.72b	<0.5^x
OM (g kg^{-1})	704a	618b	324e	335d	441c	330e	>800^x
C/N	54.78b	29.84d	71.84a	26.25e	30.71c	31.14c	20–40^x
C	412.02a	365.25b	189.66e	195.86d	258.63c	194.32d	–
N (g kg^{-1})	7.52c	12.24a	2.64e	7.46c	8.42b	6.24d	–
P (g kg^{-1})	0.50(0.08)d	14.23(4.01)a	0.21(0.06)e	8.42(2.16)c	11.24(4.12)b	8.86(2.85)c	–
K (g kg^{-1})	0.98(0.30)e	2.56(0.87)a	0.43(0.19)f	1.25(0.48)d	1.86(0. 83)b	1.48(0.67)c	–
Mg (g kg^{-1})	0.44(0.07)c	0.68(0.29)a	0.46(0.05)c	0.54(0.18)b	0.64(0.27)a	0.62(0.28)a	–
Ca (g kg^{-1})	0.51(0.20)d	0.77(0.23)c	0.71(0.24)c	0.80(0.26)b	0.82(0.27)b	0.89(0.29)a	–
Cu (mg kg^{-1})	14.32(7.08)d	60.36(26.21)a	13.18(6.86)d	41.12(19.68)c	52.42(24.73)b	42.94(22.25)c	500^y
Zn (mg kg^{-1})	20.32(8.94)d	131.42(37.66)a	22.48(9.13)d	81.24(29.78)c	104.04(38.30)b	86.96(34.76)c	1500^y
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	ND	5^y
Cr (mg kg^{-1})	1.16(0.59)d	8.24(1.42)a	1.24(0.62)d	5.26(1.14)c	6.98(1.37)b	5.87(1.28)c	200^y
Mn (mg kg^{-1})	19.41(9.31)e	54.12(14.36)a	18.54(9.22)f	34.23(11.97)d	45.23(13.22)b	40.68(12.74)c	–
Pb (mg kg^{-1})	1.26(0.50)f	24.32(4.15)a	2.97(0.68)e	15.17(3.48)d	19.47(3.96)b	17.27(3.75)c	1000^y

Values are means (n = 5). Within each row values followed by different letters are significantly different based on Duncan's test (p < 0.05). EC, electrical conductivity; OM, organic matter. x and y: optimal ranges and limit values in growing media according to Abad et al. [56]. Values within the parentheses are exchangeable content for K, Mg and Ca, available or extractable content for other elements.

[20,50,51,53]. Although there is no single, ideal growth medium for nursery-produced horticultural crops [23,24], most greenhouse-grown species display better growth at slight acid pH values (5.2–7.0)[50,54,55]; mixtures with SSC, SA and peat approach these values. The electrical conductivity (EC) values of the growth media were strongly affected by the addition of SSC. Our results were supported by a previous study conducted by Grigatti et al. [2]. The EC values of the mixtures with SSC exceeded the limit for an ideal substrate (<0.5 dSm^{-1}) suggested by Abad et al. [45]. Moreover, high EC of SSC can be reduced by adding SA and peat. Abad et al. [45] stated that a value for total organic matter above 800 g kg^{-1} is adequate for potting media. OM content in all media was lower than the minimum recommended value. The highest OM content of the peat media was significantly decreased with the addition of SA and the SSC. This may be due to the low amount of OM in the SA and the SSC compared to the peat media. Addition of sewage sludge based compost to the peat media decreased the OM content in the growth media compared to peat [3,50]. The N content of the growth media ranged between 2.64 and 12.24 g kg^{-1}. The highest N content was given by T2 media having SSC and peat while the lowest given by T3 where peat and SA in the media. The original N content of the SSC, peat and SA were 16.41, 7.52 and 0.4 g kg^{-1}, respectively. T1 and T4 did not show any significant difference in N content. N content of the T5 was significantly higher than the peat control while T6 is significantly lower than the peat control. Mixing SSC with comparatively low N containing peat and SA resulted low N in the growth media compared to the SSC. The C/N ratio varied between 26.25 and 71.84. The ideal established C/N ratio for a potting media is 20–40 [56]. C/N ratio of T2, T4, T5 and T6 were in the established ideal range. It is evident that SSC addition declined the C/N ratio compared to peat control. Wilson et al. [57] found that an increased proportion of compost in crop substrates prompted a decline in the C/N ratio compared to peats, although this will depend on the proportion of each ingredient in the mixture. Total and available P concentrations in SSC based media were higher than that of peat control. This is due to the high P concentration in the SSC (Table 1). The presence of SSC in the media mixture increased the total and exchangeable concentrations of K, Mg and Ca compared to peat control. Many authors have shown the use of sewage sludge generally increases the heavy metal contents in compost [2,24,58]. The presence of high levels of micronutrients or potentially toxic elements in sewage sludge would be a serious constraint for propagating media preparation. In the present study, total and extractable content Cu, Zn, Cr, Mn and Pb in the SSC based media were increased significantly compared to peat control but they always remained below the limits reported by Abad et al. (Table 4) [56] and those recommended by the United States Environmental Protection Agency (USEPA) [59]. Cd were not detected in any media. Nevertheless, the total contents of Cd, Cr, Cu, Pb and Zn in SSC and SSC-SA based media did not exceed the limits [59] for land application of sewage sludge recommended by the United States Environmental Protection Agency (Tables 1 and 4). Therefore, the SSC and SSC-SA 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).

3.2. Plant growth and production

In general, significant increases in the dry and fresh weight of shoot and root parts of lettuce plant in SSC-peat (T2) and SSC–SA based media (T4, T5 and T6) compared to peat control were observed (Table 5). Similar effects of composts addition to growth media have been referred to by other researchers [2,6,24,58,60], which were mainly due to the great contribution of nutrients, especially N and P by composts. Sanchez-Monedero et al. [61], in experiments using substrates obtained by mixing composts from

Table 5
Effects of different substrates on the growth of lettuce.

Treatments	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)
T1	91.16e	3.42d	11.42d	1.12d
T2	100.22c	3.71c	11.83c	1.21c
T3	90.65e	3.36d	11.37d	1.09d
T4	94.54d	3.68c	11.75c	1.20c
T5	131.65a	4.43a	12.48a	1.36a
T6	111.73b	3.96b	12.12b	1.26b

Values are means (n = 5). Within each column values followed by different letters are significantly different based on Duncan's test (p < 0.05).

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 T5, where SSC, SA and peat were present as 40%, 20% and 40% of the total volume, respectively. The shoot fresh weight, shoot dry weight, root fresh weight and root dry weight obtained from the T5 were increased by 44.42%, 29.53%, 9.28% and 21.43%, respectively compared to peat control. The second highest yield parameters were given by T6, which showed increased shoot fresh weight, shoot dry weight, root fresh weight and root dry weight by 22.56%, 15.79%, 6.13% and 12.50%, respectively compared to peat control. Plant growth and yield parameters of T1 and T3 did not show any significant difference. These increased biomass results may be due to the increased concentrations of plant macro and micro nutrients such as P, K, Mg, Ca, Mn, Cu and Zn in the growing media compared to the T1 and T3 media. T2, T4, T5 and T6 reported increased amount of exchangeable cations and extractable trace elements in the mixture compared to T1 (Table 4). Moreover, T2 and T5 gave higher N content compared to peat control. The lowest growth and yield parameters of the T1 and T3 may be due to the low concentrations of available nutrients compared to SSC based media. The reduced growth and yield parameters of the T4 compared to other SSC based media may be due to the high EC of the media. The increases in biomass production with the use of sewage sludge based composts as substrate components have been also reported by other authors [6,24]; this could be due to the fertilizing capacity of this compost. Furthermore, it is possible that other growth enhancing factors resulting from mixing SSC with peat may have indirectly involved in the improvement of plant growth. Such factors could include humic substances, enzymatic activities, microbial activities, which produce growth stimulating plant hormones, or increased number of beneficial microorganisms [62]. Such kind of investigations on humic substances, enzymatic activities and microbial assays should be conducted in future studies. On the other hand, the inclusion of SA in the substrates T3, T4, T5 and T6 at the rates of 20% or 40%, did not pose any constraint for plant growth compared to peat control. In summary, lettuce grew better in the assayed SSA-peat and SSC-SA media than in the peat control substrate. These results seem to indicate that these SSC-peat and SSC-SA based media may be a viable alternative to peat for containerized production of lettuce.

3.3. Element concentrations in plant shoots

Element concentrations in plant tissues are given in Table 6. It is evident that N, P, K, Mg and Ca concentrations of the plants obtained from SSC-peat and SSC-SA based media were increased compared to plants grown in peat control. Increased amounts of N, P, K, Mg and Ca in broccoli plants grown in a media containing 50% of composted sewage sludge and 50% peat were reported in a experiment conducted by Perez-Murcia et al. [24]. These increased element concentrations in the lettuce tissues could be attributed to the higher concentration of this elements observed in the SSC. N content of all substrates were above the deficiency level of 15 g kg^{-1} according to Chapman [63]. Poole et al. [54] reported that the optimal range of P for potting is 1.5–3.0 g kg^{-1}. Comparing our findings P contents of the plants grown in T2, T4, T5 and T6 substrates were observed that they were within the optimal values. The P values of plants grown in T1 and T3 substrates were below the optimal range. Shoot K, Ca and Mg contents were all above the deficiency limit of 7–15 g kg^{-1} [63], 1.4 g kg^{-1} [64] and 0.6 g kg^{-1} [63], respectively. Positive effects on plant nutrition derived from using composted sewage sludge in growing media have been reported in literature [23,26]. Therefore, a combination of peat with composts and other residual products (e.g., fresh pine bark, pruning waste, green waste, paper waste) can minimize the negative properties of a single material, thus obtaining sound and cheap substrates [23,65]. Cu, Cr and Pb concentrations in the plant tissues obtained from assayed media did not show any significant difference with the plant tissues obtained from the peat control. Pb concentrations in broccoli plant tissues obtained from a media containing composted sewage sludge and peat did not show any significant difference compared to broccoli plants obtained from peat control [24]. Zn concentration of the lettuce plant tissues obtained from assayed media showed significant increase compared to peat control. Similar results were reported in a previous study conducted by Perez-Murcia et al. [24]. In general, none of the trace elements studied reached phytotoxic levels in plants (the growth was not affected). In general, Cu, Mn, Zn, Cd, Cr and Pb concentrations in plants tissues obtained from all media were far lower than the phytotoxic ranges [66], and in some cases even lower than the ranges considered normal for plants [67]. Organic amendments such as sludge composts or peat, which contain high proportion of humified organic matter, can decrease the bioavailability of heavy metals by adsorption and by forming stable complexes with humic substances [68,69]. The highest Mn content was reported in T1 and T3. 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 [23]. For Mn, a concentration decrease derived from the composts application have been reported by other authors [70,71,72]. A possible dilution effect derived from the greater biomass reached by the plants grown in the SSC based substrates could also cause these comparatively low concentrations of Mn in relation to T1 and T3 substrates as described by Perez-Murcia et al. [24]. The evaluation of heavy metals in the plant tissues are important in order to avoid food chain hazards. The permitted values for consumption of Cd and Pb, in horticultural crops are 0.2 and 0.3 mg kg^{-1}, respectively, on a fresh weight basis [73]. In the present experiment, Cd were not detected and Pb level was below these values, considering the water content of lettuce. The extraction ratios of trace elements

Table 6
Element concentrations in plant shoots.

Elements	T1	T2	T3	T4	T5	T6	Normal range	Phytotoxic range
N (g kg^{-1})	22.44b	24.32a	21.21b	23.46a	24.28a	23.17a		
P (g kg^{-1})	0.61c	1.56b	0.68c	1.68a	1.66a	1.58b		
K (g kg^{-1})	12.24b	18.43a	11.88c	18.12a	18.21a	18.09a		
Mg (g kg^{-1})	3.88c	4.89a	3.74c	4.12b	4.83a	4.24b		
Ca (g kg^{-1})	10.21b	11.23a	9.88c	11.12a	11.45a	11.20a		
Cu (mg kg^{-1})	3.88a	3.82a	3.91a	3.77a	3.70a	3.76a	3–20^{y}	25–40^{x}
Mn (mg kg^{-1})	101.24a	88.12b	100.36a	89.32b	86.12b	84.25b	15–150^{y}	400–2000^{x}
Zn (mg kg^{-1})	20.37b	22.15a	19.23b	23.12a	24.29a	23.21a	15–150^{y}	500–1500^{x}
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	ND	0.1–1^{y}	5–700 x
Cr (mg kg^{-1})	0.44a	0.51a	0.40a	0.47a	0.46a	0.44a	0.02–14^{y}	–
Pb (mg kg^{-1})	0.51a	0.54a	0.47a	0.45a	0.48a	0.46a	2–5^{y}	–

Values are means (n = 5). Within each row values followed by different letters are significantly different based on Duncan's test (p < 0.05). x and y: phytotoxic and normal range values according to Romheld and Marschner [66] and Adriano [67], respectively.

Table 7
Comparative effects of the different growing media studied on trace elements (Cu, Zn, Cr and Pb) extraction ratios (total trace elements taken up by the plant versus extractable trace elements in growth media before planting).

Treatment	Cu	Zn	Cr	Pb
T1	0.55a	2.28a	0.75a	1.02a
T2	0.15b	0.59c	0.36b	0.13c
T3	0.57a	2.11a	0.65a	0.69b
T4	0.19b	0.78b	0.41b	0.13c
T5	0.15b	0.63c	0.34b	0.12c
T6	0.17b	0.67c	0.34b	0.12c

Values are means ($n = 5$). Within each column values followed by different letters are significantly different based on Duncan's test ($p < 0.05$).

into plant tissues expressed as trace elements concentrations in plant versus extractable trace elements in the growth media are given in Table 7. Highest extraction ratios for Cu, Zn, Cr and Pb were in the plant tissues were obtained from the plants grown in peat control (T1) and Peat – SA (T3) media. Similar results were reported by Perez-Murcia et al. [24]. Pitchel and Anderson [74] observed an insignificant effect on concentrations of Cr and Pb in oat grown on soils amended with composted municipal solid waste or composted sewage sludge. Concentrations of Pb, Ni, Cu, and Cd in roots and leaves of *Dactylis glomerata* were unrelated to the total or DTPA-extractable concentrations in the sludge-amended soil [75]. Therefore, it can be concluded that increased concentrations of total and extractable trace elements in SSC based growth media did not increase the trace element concentrations in plant tissues compared to peat control.

4. Conclusions

It can be concluded that, in general, the substrates elaborated with SSC and SA showed suitable physical and chemical properties, absence of phytotoxicity and important nutrient contents. Although, these substrates showed pH and EC values higher than pure peat, which can constitute the main limiting factor for their use as growing media, they did not induce any reduction in plant growth. Increased biomass production of lettuce was reported from the SSC-peat and SSC-SA assayed media compared to peat media. Moreover, due to physical and chemical characteristics of the media developed by SSC and SA, SSC-SA based media can be considered as valuable partial peat substitutes for lettuce, especially at the rates of 40% of SSC, 20% of SA and 40% of peat, which gave the maximum growth parameters and the highest biomass yield of the lettuce when compared to peat. Therefore, the SSC and SA developed by using sewage sludge, sugarcane trash, paper waste and low productive soil can be considered as a suitable method for recycling and reducing the environmental impact of these residues.

Acknowledgement

Most sincere thanks and appreciation are extended to the Higher Education Ministry of Japan (Monbukagakusho) for the financial support granted to conduct this study. Thanks are also due to all members of Department of Environmental Science and Technology, Faculty of Agriculture, University of the Ryukyus, Japan for their assistance given through out the period of study.

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