TECHNICAL PAPER

Improvement of salinity in sewage sludge compost prior to its utilization as nursery substrate

Hong-tao Liu, Ding Gao,* Tong-bin Chen, Hong Cai, and Guo-di Zheng

Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

**Please address correspondence to: Ding Gao, Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; e-mail: gaod@igsnrr.ac.cn*

Soluble salts are enriched in sewage sludge compost because of their inherent derivation. Accordingly, the content of soluble salt in sludge compost is usually much higher than most seedlings can tolerate. To determine whether sludge compost is suitable for use as a nursery substrate, some experiments were conducted. Reduction of the electrical conductivity (EC) value could improve seed germination in saturated extract from sludge compost. In addition, water elution and mixing dilution with raw soil were all shown to be able to alleviate saline inhibition on seed germination and seedling growth, including stem diameter, seedling height, and above-ground weight. Overall, salinity is a crucial problem when sewage sludge compost is reused as a nursery substrate, and some effective and convenient approaches to reduce salt should be served prior to its reuse.

Implications: Sewage sludge after being composted is usually reused as organic fertilizer or plant substrate. However, salt is the main problem during its reclamation. What is the highest salt level the seedling can tolerate? Which types of salts are effective in salinity of sludge-amended substrate? Meanwhile, can the salinity be reduced through water elution or soil mixing dilution? This paper is the first to investigate the salinity and its reduction of sewage sludge compost prior to its use in the development of nursery substrate.

Introduction

Sewage sludge, which is the solid by-product of treatment of household derived sewage, has positive effects on the physical, chemical, and biological properties of soil or substrates that it is added to (Lakhdar et al., 2010). Specifically, amendment with sewage sludge leads to improved porosity (Cai et al., 2010), enhanced water binding capacity (Navas et al., 1998; Chen et al., 2002), and increased biomass or nutrient uptake (Jayasinghe, 2012; Gasco and Lobo, 2007; Grigatti et al., 2007; Perez-Murcia et al., 2006). However, most residual salts are transferred and deposited into the sludge during treatment. Uptake content of heavy metal increases along with the increase in sludge compost amend dose, but not to a threshold value of physiological disorder or injury, even only slight biotoxicity (Hicklenton et al., 2001) compared to salt (Singh and Agrawal, 2008), whose toxicity has more stronger negative effect on seedling growth. Salt content in nursery substrate amended by sludge compost usually is beyond the physiological tolerance threshold, so the main obstacle to application of sludge compost to agricultural substrate is salt excess.

Accordingly, salinity is one of the main problems hindering the reclamation of sewage sludge via application as soil amendments or substrates (Chong, 2005; Chong and Purvis, 2004; Cai et al., 2010). As a result, the utilization of sludge may increase soil salinity (Chong and Purvis, 2004), which can be especially problematic when it is used as a nursery substrate due to the increased sensitivity of seedlings to salt. Despite this, no detailed studies to determine the most common types of salt in sludge or which types are most damaging to young plants have been conducted. Moreover, no simple and suitable methods for modification of sewage sludge compost to be used as nursery substrate to reduce salinity stress have been investigated to date.

Several studies have reported that an increased proportion of sewage sludge compost to substrate is positively correlated with plant growth to a point above which adverse effects on seedlings will occur (Ozdemir et al., 2004; Cai et al., 2010; Ostos et al., 2008). This reversible change in the growth, to a great degree, has been attributed to the accumulation of salinity caused by incremental sewage sludge amendment, as well as concomitant crescent contents of heavy metals and organic acids introduced by sewage sludge. Koushafar et al. (2011) showed that zeolite can reduce the salinity of compost produced from sewage sludge; however, they did not consider material cost and source problems in their investigation. In the present study, a convenient and economic method for utilization of sewage sludge compost as a nursery substrate was explored. The main types of inorganic salt in sewage sludge compost were identified, after which saturated aqueous extract was assayed to determine salinity ranges suitable for germination and growth. Subsequently, water elution and mixing dilution with raw soil were attempted to reduce salinity in sludge amended substrate.

Journal of the Air & Waste Management Association, 64(5):546–551, 2014. Copyright © 2014 A&WMA. ISSN: 1096-2247 print
DOI: 10.1080/10962247.2013.872710 Submitted August 12, 2013; final version submitted October 31, 2013; accepted December 1, 2013.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uawm.

Materials and Methods

Sewage sludge was taken from a municipal wastewater treatment (wastewater characteristics including biological oxygen demand [BOD_5], chemical oxygen demand [COD] and suspended solid [SS] concentrations are 10.7 mg L^{-1}, 49.6 mg L^{-1}, and 16.5 mg L^{-1}, respectively). The technology of wastewater treatment is the conventional activated sludge process. The technology of sludge treatment is air flotation thickening, by which the water content is lowered from 97% to 94%, and then thickened sludge is centrifugally dewatered; after that, the water content of sludge is reduced from 94% to 81% after centrifugal dewatering. Material came from a plant in Qinhuangdao (Hebei Province, China) and was mixed with sawdust at a 1:1 ratio by volume. The resulting mixture was then composted in a static forced aeration device for 30 days, after which the finished compost was placed in a storehouse and allowed to age for 5 months. The mature compost was then air dried and passed through a 10-mm sieve.

Next, 50 g of compost was soaked in 250 mL deionized water, shaken for 4 hr at room temperature, and then filtered through quantitative filter paper, after which the filtrate was assayed to identify the inorganic salt types. Subsequently, 50 mL of the filtrate was evaporated at 100°C in a water bath, during which time 10 mL of 30% H_2O_2 was added to eliminate disturbance of the organic matter. The samples were then diluted to develop a salinity series of electrical conductivity (EC) of 1.5, 2.5, 3.5, and 4.5 dS cm^{-1} (labeled E1, E2, E3, and E4, respectively), after which the diluted samples (5 mL) were spread on culture dishes covered with filter paper. Seeds were sown on the dishes and they were transferred to a dark room with a temperature of 30°C and 35–60% relative humidity for germination. Finally, the seed shoot length, germination percentage, and germination index (GI, [germination percentage × seed shoot length/germination percentage of control × seed shoot length of control] × 100%) were determined.

In the water elution experiment, sewage sludge compost samples were added to deionized water at ratios of 1:0, 1:1, 1:2, and 1:3 (w/w, labeled T0, T1, T2, and T3 respectively), and the mixtures were stirred thoroughly, then soaked for 12 hr. Subsequently, compost sample was spread on gauze with a diameter of 50 μm and allowed to drain. The eluted compost was then mixed with perlite to form a nursery substrate.

In the mixing dilution experiment, sewage sludge compost samples were mixed with raw soil, whose EC value is 0.2 dS cm^{-1} and that was taken from near farmland. Then the mixture was beaten well at a series of dilution ratios (Table 1) to develop nursery substrate. The effect of dilution was compared to a mixture of peat and perlite regarded as the traditional nursery substrate.

Tomato and lettuce seeds were sown in treated substrate and allowed to grow for 30–35 days, at which time the seedlings were harvested and the biomass (above-ground, oven dried), shoot length, and stem diameter were measured to evaluate the effects of salinity on seedling growth.

EC was determined using an Orion 310C-01 conductimeter (Bower and Wilcox, 1965). To measure the Na, K, Ca, Mg, Fe, Mn, Cu, Zn, and Si, the extract was diluted 10 times and then analyzed using an inductively coupled plasma–optical emission spectrometer (ICP-OES). The Cl was determined via the precipitation titration method (Mohr's method, ISO 9297-1989). All data were statistically analyzed using analyses of variance (ANOVAs) at a significance level of $P < 0.05$ with SPSS v.13.0.

Table 1. Composition of sewage sludge compost-based substrate

	Material proportion (w/w)		
Treatment	Sewage sludge compost (g)	Raw soil (g)	Dilution ratio
D1	10	90	10
D2	20	80	5
D3	30	70	3.3
D4	40	60	2.5
D5	50	50	2
Control (CK)	Peat/perlite mixture in 3:1		

Results and Discussion

Properties of soluble salts in saturated sewage sludge compost

As shown in Table 2, the electrical conductivity (EC) of saturated sewage sludge compost was 5.01 dS cm^{-1}, which was about 25-fold higher than that of the background soil. It has been reported that the value of EC exceeding 1.8 dS cm^{-1} can lead to salt stress for most plant seedlings (Pascale and Barbieri, 1995). The EC of saturated sewage sludge compost is much higher than the threshold just mentioned, indicating that untreated or modified sludge cannot be used directly as a nursery substrate. For most herbaceous and woody seedlings, Na and Cl salinity tolerance values range from 300 to 800 mg L^{-1} and from 500 to 1000 mg L^{-1}, respectively (Jaleel et al., 2007; Romero-Aranda et al., 2001; Okubo and Sakuratani, 2000). Obviously, the Na and Cl levels (935 and 1083 mg L^{-1}, respectively) in the sewage sludge compost are beyond the tolerance ranges for these plants. Moreover, the K, Ca, and Mg contents of saturated compost were also higher than those of background soil. However, the Fe, Mn, Cu, Zn, and Si contents of saturated compost and soil were within one order of magnitude of each other. It follows that utilization of sewage sludge compost as nursery substrate will be limited because of enriched salts, especially soluble Na, Cl, K, Ca, and Mg ions. It is evident that sludge compost will yield salinity stress if these ions are not reduced or diluted prior to substitution for traditional nursery substrate.

Inhibition of salinity in sewage sludge compost extract on seed germination

As shown in Figure 1, the seed shoot length, germination percentage, and GI of tomato and lettuce all declined in an inverse proportional manner as the EC of sludge compost extract increased (from 1.5 dS cm^{-1} to 4.5 dS cm^{-1}). These results support the conclusion that a low EC value is beneficial to

Table 2. Content of soluble salts in saturated extract of sewage sludge compost and background soil

Parameter	Sewage sludge compost	Background soil	Ratio of sewage sludge compost/soil
EC (dS cm^{-1})	5.01	0.20	25.1
Na (mg L^{-1})	935	12.21	76.6
K (mg L^{-1})	753	24.29	31.0
Ca (mg L^{-1})	3684	131	28.1
Mg (mg L^{-1})	658	29.9	22.0
Cl (mg L^{-1})	1083	53.25	20.3
Mn (mg L^{-1})	0.32	0.04	8.0
Si (mg L^{-1})	39.46	21.59	1.8
Zn (mg L^{-1})	0.19	0.15	1.3
Cu (mg L^{-1})	0.25	0.30	0.8
Fe (mg L^{-1})	0.42	1.27	0.3

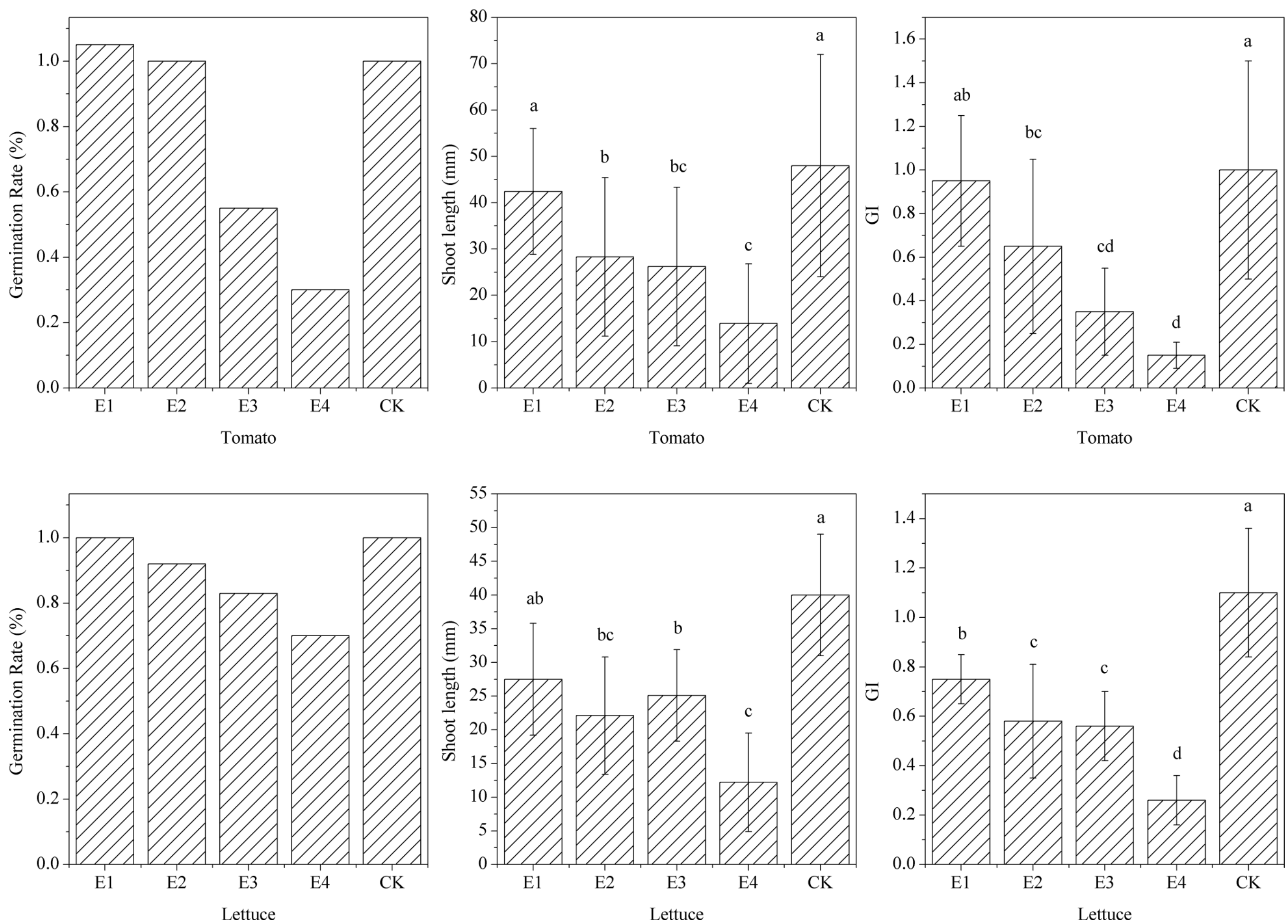

Figure 1. Comparison of germination rate, seed shoot length and GI (germination index) of tomato and lettuce cultivated in sewage sludge compost extract with different EC values.

seedling emergence in compost-amended substrate reported by Burger et al. (1997) and Pinamonti et al. (1997). These findings indicate that seed germination was gradually improving along with decrease in EC of sludge compost extract. It is worth noting that germination percentage of 1.5 dS cm^{-1} treatment was higher than for the control (water treatment) for tomato. This unexpected case, to some extent, implies that salt balance is more essential for seed germination, rather than blind reduction. Ribeiro and Santos (1997) reported that substrates with high EC values reduce water retention and imbibing, negatively

Table 3. Content of soluble salts in saturated extract of sewage sludge compost and background soil after water elution

Parameter (mg L^{-1})	Without water elution (T0)	Onefold water volume with elution (T1)	Twofold water volume elution (T2)	Threefold water volume elution (T3)	CK (background soil)
Na	935	609	421	329	12.21
K	753	544	404	313	24.29
Ca	3684	2308	1615	1188	131
Mg	658	401	278	206	29.9
Cl	1083	682	408	320	53.25

affecting the germination process. Therefore, based on these results and referenced conclusions, optimal salt concentration range of saturated sludge is vital for direct use as a nursery substrate for seed germination, neither too high nor too low.

Water-eluted sewage sludge compost as a nursery substrate increases seedling biomass

Since sewage sludge compost is enriched in soluble salts, water elution should be a feasible method of eliminating excessive saline effects. Noguera et al. (1997) demonstrated that excess soluble salts were effectively leached from nursery material by irrigation when organic waste was used as substrate. As a convenient salinity reduction method, water elution can remove most soluble salts despite the risk of some nutrients being wasted. In this study, the soluble salt (including Na, K, Ca, Cl, and Mg) contents in saturated extract of sewage sludge compost decreased as the volume of water consumed increased from onefold to threefold (Table 3). When the volume of water eluted was 1 times the volume of extract, the contents of Na (609 mg L^{-1}) and Cl (682 mg L^{-1}) approached their tolerance values range (Na: 300–800 mg·L^{-1}; Cl: 500–1000 mg L^{-1}, mentioned in Noguera et al., 1997, chapter 3.1). When the volume of water eluted reached 3 times, the Na, Ca, Mg, and Cl content decreased to one-third of that of treatment without water elution.

Hicklenton et al. (2001) found that municipal-waste-amended substrate had no significant effect on EC value or biological growth when compared to a control after long-term water elution. In this study, significant changes in biological indices including stem diameter, seedling height, and above-ground weight resulted from substitution of eluted sewage sludge compost as nursery substrate. As shown in Figure 2, for tomato seedlings, when the

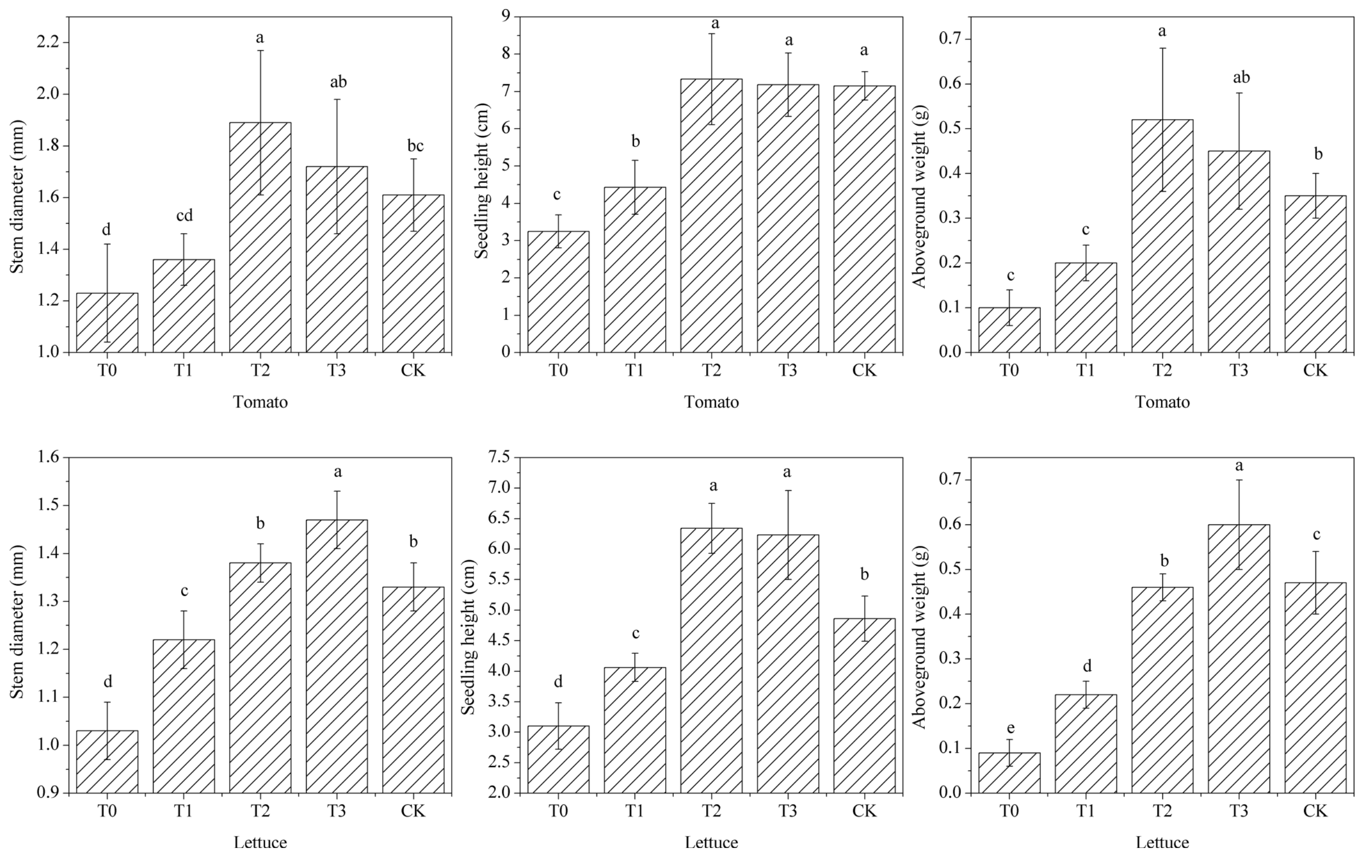

Figure 2. Comparison of stem diameter, seedling height, and above-ground biomass of tomato and lettuce cultivated in sludge compost prepared as nursery substrate using different volumes of water eluted.

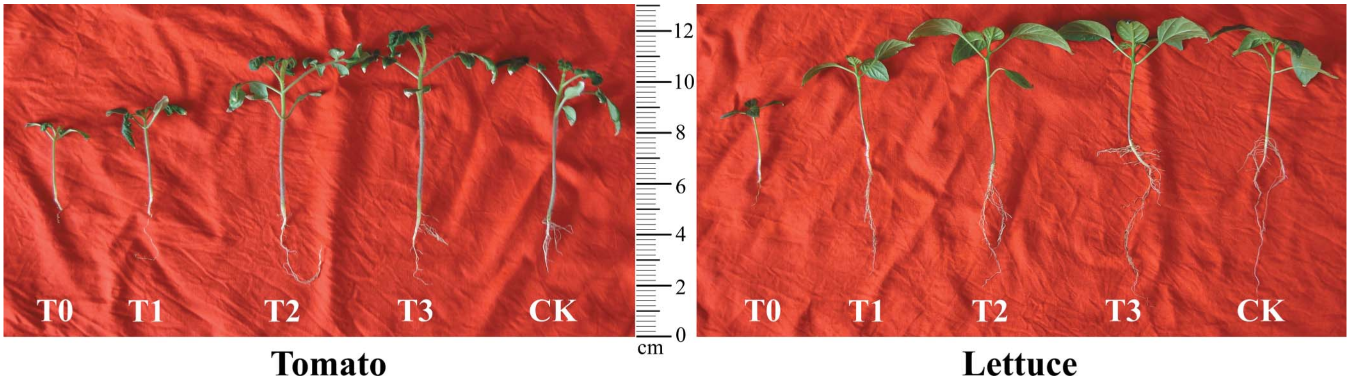

Figure 3. Effect of water elution of sewage sludge compost used as nursery substrate on seedling growth of tomato (a) and lettuce (b).

Table 4. Effect of mixing sewage sludge compost with raw soil as nursery substrate on biological indices of tomato and lettuce

	Stem diameter (mm)		Seedling height (cm)		Above-ground weight (g)	
Treatment	Tomato	Lettuce	Tomato	Lettuce	Tomato	Lettuce
D1	3.21 a*	1.85 a	12.13 a	8.93 a	0.22 a	0.15 a
D2	3.15 a	1.80 a	11.45 a	8.32 ab	0.21 a	0.11 ab
D3	3.02 ab	1.69 b	9.98 ab	7.27 b	0.16 ab	0.12 ab
D4	2.76 b	1.63 b	9.60 b	6.77 c	0.14 b	0.09 b
D5	2.87 ab	1.63 b	9.52 b	6.98 bc	0.15 b	0.08 b
CK	3.11 a	1.76 ab	10.48 a	8.25 ab	0.20 a	0.15 a

Note: *Means with the same letter are not significantly different for $p \leq 0.05$.

amount of water eluted was increased to twofold the volume (T2), the maximum stem diameter and above-ground weight were attained and the seedling height was similar to that obtained when the amount of water eluted was threefold the water volume (T3) and to that of the background soil (CK). Similarly, the maximum values for lettuce seedlings appeared in T3 followed by T2. Taken together, these findings indicate that biological performance made an improvement along with increase in volume of water eluted. The results of seedling growth were in agreement with these finding (see Figure 3).

Mixing sewage sludge compost with raw soil as nursery substrate alleviates saline inhibition of biomass

In addition to the effects of water elution, we investigated whether it was feasible to mix sewage sludge compost with raw soil to dilute the salinity. As the mixing dilution ratio increased, the stem diameter, seedling height, and above-ground weight all increased significantly (Table 4). When the dilution ratio was greater than 5.0 (D1 and D2 in Table 4), the biological indicators were equal to those of the control treatment. Zeolite is a suitable agent to reduce salinity, and its addition in levels as low as 15% has exhibited a 42% decrease in salinity (Koushafar et al., 2011). However, the addition of zeolite has been shown to lead to excessive adsorption and ion exchange, resulting in loss of nutrient salts, so this may backfire in terms of effect of substrate on seedling growth. Herrera et al. (2008) reported that incremental addition of peat to compost substrate could improve seedling indices. Regardless of whether zeolite or peat is used, the addition will be limited by material cost and availability. Conversely, raw soil is easy to obtain and inexpensive. This finding presents the potential to reduce salinity in sludge-compost-based substrate using convenient and handy raw soil.

Conclusion

As a reclaimable resource, sewage sludge compost has advantageous properties in plant nutrient and organic matter, making it a good nursery substrate. However, it is enriched in soluble salts such as Na, K, Cl, Mg, and Ca, which may inhibit seed germination and seedling growth. If soluble salt concentrations balanced in a reasonable range, the seed germination was not negatively affected. Water elution and mixing dilution were validated to be effective for alleviating saline stress on seedling growth. Along with the increase in volume of water eluted or the decrease in mixing proportion of raw soil, recovery of seed emergence and seedling biological performance appeared. Overall, salinity is a negative factor associated with sewage sludge compost that can be ameliorated through relatively simple and effective methods such as water elution or mixing dilution with raw soil when preparing nursery substrate.

Funding

This study was financially supported by Beijing Nova Program (Z121109002512061), Exploratory Forefront Project for the Strategic Science Plan in IGSNRR, CAS (2012QY005), National High-Tech Research and Development Program of China (2009AA064702), and Agricultural Science & Technology Achievement Transformation Fund Project of China (2012GB24910651).

References

Bower, C.A., and L.V. Wilcox. 1965. *Methods of Soil Analysis. Part 2*, 937–40. Madison, WI: American Society of Agronomy.

Burger, D.W., T.K. Hartz, and G.W. Forister. 1997. Composted green wastes as a container medium amendment for the production of ornamental plants. *Hortscience* 32(1): 57–60.

Cai, H., T.B. Chen, H.T. Liu, D. Gao, G.D. Zheng, and J. Zhang. 2010. The effect of salinity and porosity of sewage sludge compost on the growth of vegetable seedlings. *Sci. Horticult*. 124:381–86. doi:10.1016/j.scienta.2010.01.009

Chen, T.B., D. Gao, and X.B. Li. 2002. Effects of sewage sludge compost on available nutrients and water retention ability of planting substrate. *Acta Ecol. Sin*. 22(6): 802–7.

Chong, C. 2005. Experiences with wastes and composts in nursery substrate. *HortTechnology* 15:739–47.

Chong, C., and P. Purvis. 2004. Raw and composted paper mill sludges and municipal compost in nursery substrates. *Hortscience* 39(4): 818.

Gasco, G., and M.C. Lobo. 2007. Composition of a Spanish sewage sludge and effects on treated soil and olive trees. *Waste Manage*. 27:1494–500. doi:10.1016/j.wasman.2006.08.007

Grigatti, M., M.E. Giorgioni, and C. Ciavatta. 2007. Compost-based growing media: Influence on growth and nutrient use of bedding plants. *Bioresource Technology* 98:3526–34. doi:10.1016/j.biortech.2006.11.016

Herrera, F., J.E. Castillo, A.F. Chica, and L. López-Bellido. 2008. Use of municipal solid waste compost (MSWC) as a growing medium in the nursery production of tomato plants. *Bioresource Technol*. 99:287–96. doi:10.1016/j.biortech.2006.12.042

Hicklenton, P.R., V. Rodd, and P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bark composts as components of container growing media. *Sci. Horticult*. 91(3–4): 365–78. doi:10.1016/S0304-4238(01)00251-5

Jaleel, C.A., R. Gopia, B. Sankara, P. Manivannana, A. Kishorekumara, R. Sridharana, and R. Panneerselvam. 2007. Studies on germination, seedling vigour, lipid peroxidation and proline metabolism in Catharanthus roseus seedlings under salt stress. *South Afr. J. Bot*. 73:190–95. doi:10.1016/j.sajb.2006.11.001

Jayasinghe, G.Y. 2012. Sugarcane bagasses sewage sludge compost as a plant growth substrate and an option for waste management. *Clean Technol. Environ. Policy* 14(4): 625–32. doi:10.1007/s10098-011-0423-8

Koushafar, M., A.H. Khoshgoftarmanesh, and F. Aghili. 2011. Natural zeolite reduces salinity and heavy metal availability of compost produced from sewage sludge-rose residue mixture. *J. Residuals Sci. Technol*. 8(1): 9–14.

Lakhdar, A., R. Scelza, R. Scotti, M.A. Rao, N., Jedidi, L. Gianfreda, and C. Abdelly. 2010. The effect of compost and sewage sludge on soil biological activities in salt affected soil. *J. Soil Sci. Plant Nutr*. 10(1): 40–47.

Navas, A., F. Bermúdez, and J. Machín. 1998. Influence of sewage sludge application on physical and chemical properties of gypsisols. *Geoderm*a 87:123–35. doi:10.1016/S0016-7061(98)00072-X

Noguera, P., M. Abad, R. Puchades, V. Noguera, A. Maquieira, and J. Martinez. 1997. Physical and chemical properties of coir waste and their relation to plant growth. *Acta Horticult*. 450:365–73.

Okubo, M., and T. Sakuratani. 2000. Effects of sodium chloride on survival and stem elongation of two Asian pear rootstock seedlings. *Sci. Horticult*. 85(1–2): 85–90. doi:10.1016/S0304-4238(99)00141-7

Ostos, J.C., R. Lopez-Garrido, J.M. Murillo, and R. Lopez. 2008. Substitution of peat for municipal solid waste- and sewage sludge-based composts in nursery growing media: effects on growth and nutrition of the native shrub *Pistacia lentiscus* L. *Bioresource Technol*. 99(6): 1793–800. doi:10.1016/j.biortech.2007.03.033

Ozdemir, S., O.H. Dede, and G. Koseoglu. 2004. Recycling of MSW compost and sewage sludge as growing substrate for ornamental potted plants. *Fresenius Environ. Bull*. 13(1): 30–33.

Pascale, S.D., and G. Barbieri. 1995. Effects of soil salinity from long-term irrigation with saline-sodic water on yield and quality of winter vegetable crops. *Sci. Horticult*. 64:145–57. doi:10.1016/0304-4238(95)00823-3

Perez-Murcia, M.D., R. Moral, J. Moreno-Caselles, A. Perez-Espinosa, and C. Paredes. 2006. Use of composted sewage sludge in growth media for broccoli. *Bioresource Technol*. 97:123–30. doi:10.1016/j.biortech.2005.02.005

Pinamonti, F., G. Stringari, and G. Zorzi. 1997. Use of compost in soilless cultivation. *Compost Sci. Utilization* 5(2): 38–46. doi:10.1080/1065657X.1997.10701872

Ribeiro, H.M.F., and J.Q. Santos. 1997. Utiliçao de residuos sólidos urbanos comportados na formulaçao de sustratos: Efeito nas propiedades físicas e químicas dos sustrato. *Actas de Horticultura*, Vol. 18-II. Congreso Iberoamericano e III Congreso Ibérico de Ciencias Hortícolas. 11–15 Março, Vilamoura, Portugal.

Romero-Aranda, R., T. Soria, and J. Cuartero. 2001. Tomato plant-water uptake and plant-water relationships under saline growth conditions. *Plant Sci*. 160: 265–72. doi:10.1016/S0168-9452(00)00388-5

Singh, R.P., and M. Agrawal. 2008. Potential benefits and risks of land application of sewage sludge. *Waste Manage*. 28: 347–58. doi:10.1016/j.wasman.2006.12.010

About the Authors

Hong-tao Liu, **Guo-di Zheng**, and **Ding Gao** are assistant professors, **Tong-bin Chen** is a professor and **Hong Cai** is a Ph.D. candidate in Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China.