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Evaluation of Composted Sewage Sludge (CSS) as a Soil Amendment for Bermudagrass Growth

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Abstract: In order to evaluate the growth of Bermudagrass (*Cynodon dactylon* L.) in soils amended with 5-100% composted sewage sludge (CSS) and the impacts of CSS amendment on soil physical and chemical properties an experiment was conducted. Soils amended with ≤20% CSS did not significantly affect the seedling emergence, while the contents of chlorophyll, nitrogen, phosphorous and potassium of Bermudagrass grown in such soils were greatly improved. Bulk density, water retention and nutrient contents of the soil were also improved with the amendment of CSS, but high CSS contents introduced excessive amounts of heavy metals and soluble salts. Results show that Cu, Zn and Pb accumulated slightly (up to~2.3 times) in clippings of Bermudagrass grown in CSS-amended soils compared to those grown in the base and reference soils, while no significant Cd absorption in shoots of Bermudagrass occurred. The detrimental effects on seedling emergence and turfgrass growth observed on substrates with high (≥40%) CSS contents were mainly attributed to the presence of high soluble salt concentrations. The findings suggest that addition of CSS at 10-20% levels can greatly improve the soil nutrient supply for turfgrass growth without significantly affecting heavy metal and soluble salt contents of the soil.

Key words: Bermudagrass, Composted Sewage Sludge (CSS), soil nutrients, heavy metals, soil amendment

INTRODUCTION

The increasing generation of organic wastes by livestock operations, industrial activity and municipalities brings significant pressure on the waste disposal (Eghball and Gilley, 1999; Giusquiani *et al*., 1995; He *et al*., 1992). These organic wastes are typically rich in organic matter and contain high levels of Nitrogen (N) and Phosphorus (P) that are required for plant growth. Composting of raw organic wastes has been shown to have a number of agronomic benefits, including reduction in material mass and water content, pathogen suppression, decreased weed seed viability and the production of a stabilized organic material that is easier to handle and spread (Eghball and Gilley, 1999; Parkinson *et al*., 2004). Moreover, the resulting compost can be used to improve the growth and nutritional quality of crops and forage grasses, while reducing the needs for synthetic fertilizers (Angle, 1994). The turfgrass industry has been identified as one of the markets that can benefit from employing compost in the production and management plans. Studies have shown that the amendments with organic compost can enhance turfgrass establishment and quality compared with fertilizer sources of nutrients (Angle *et al*., 1981; Cisar and Snyder, 1992; Garling and Boehm, 2001; Landschoot and McNitt, 1994; Loschinkohl and Boehm, 2001; Norrie and Gosselin, 1996; Schumann *et al*., 1993).

Sewage sludge (also known as biosolids) is one of the final products of the treatment of sewage at wastewater treatment plants. Composted Sewage Sludge (CSS) usually contains high levels (10% to>20%) of organic matter and is rich in N and P that are essential for plant growth. Potassium (K) and micronutrients, such as zinc (Zn), copper (Cu) and iron (Fe) are also present at relatively high levels in CSS. Organic matter contributes to plant growth through its effect on the physical, chemical and biological properties of the soil (Brady and Weil, 1999). Nitrogen is an integral component of many essential plant compounds and it is a major part of proteins, nucleic acids and chlorophyll (Brady and Weil, 1999). Nitrogen is the key element for turfgrass and influences the turf color and growth rate. Bilgili and Acikgoz (2005) showed that turf color and quality were associated with N fertility treatments and that increasing nitrogen significantly enhanced the color and quality ratings of several turf mixtures. Phosphorus and potassium in the CSS also play important roles in

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turfgrass growth. Potassium is directly involved in maintaining the water status of plants, turgor pressure of cells and the opening and closing of stomata. Besides supplying organic matter, N, P and K, addition of organic amendments, including CSS, can also reduce soil bulk density and increase water infiltration rate and nutrient holding capacity of soil in turfgrass production (Angle, 1994).

Much of the research on compost utilization by the turfgrass industry has focused on the suppression of diseases (Garling *et al*., 1999; Landschoot and McNitt, 1997; Liu *et al*., 1995; Nelson and Craft, 1992), the effects of composts on physical and chemical properties of the amended soils (Giusquiani *et al*., 1995; Logan and Harrison, 1995; Pagliai and Antisari, 1993; Sims, 1990) and on the fertility of turfgrasses (Landschoot and Waddington, 1987; Norrie and Gosselin, 1996; Schumann *et al*., 1993). The effects of using composted manure as a soil amendment for turfgrass establishment and sod production have been evaluated in many studies (Cisar and Snyder, 1992; Landschoot and McNitt, 1994; Lee and Rieke, 1993; Loschinkohl and Boehm, 2001). In contrast, there have been few studies on application of CSS as a soil amendment for turfgrass production. Angle *et al*. (1981) showed that the quality of the turf increased with both time and the compost amendment rate during sod establishment and the increase in quality rating was attributed to increased amounts of nutrients from the compost. Garling and Boehm (2001) reported that compost could compete with inorganic fertilizers in the ability to enhance turfgrass color and growth.

One concern on application of CSS is its relatively high heavy metal contents, which can potentially cause soil pollution and toxic effect on plant growth. Heavy metals in sewage sludge are not destructed by composting and their presence may limit the use of CSS as a soil amendment. Sims (1990) observed that land application of cocomposted sewage sludge only had little influence on plant and soil (extractable) concentrations of Cu, Cd, Cr, Ni and Pb and concluded that increases in soil and plant concentrations of nonessential heavy metals should not be a limiting factor in compost use. Giusquiani *et al*. (1995) found that in the plots amended with urban waste compost, Pb, Cu and Zn showed significant increases compared with non-amended plots. Bioaccumulation of Cu and Zn in earthworm *Lumbricus terrestris* L. in sewage sludge-amended soils has also been observed (Kizilkaya, 2004). High concentrations of soluble salts are typically present in CSS and the potential hazard associated with high soil salinity is an important consideration for CSS utilization (Eklind *et al*., 2001; Perez-Murcia *et al*., 2006).

Because of the presence of both beneficial (nutrients and organic matter) and non-beneficial (heavy metals and soluble salts) components in CSS, it is necessary to systematically study the impacts of CSS amendment on turfgrass growth andon the soil physical and chemical properties to optimize CSS application. The objectives of this study were to (I) compare turfgrass growth in response to increasing amendment of CSS, (ii) evaluate the impact of CSS amendment on soil physical and chemical properties and (iii) identify the optimum levels of CSS amendment for turfgrass production. Growth of turfgrass, Bermudagrass, in soils with 0-100% CSS was monitored by tracking the seedling emergence date and rate and the contents of chlorophyll, nutrients and heavy metals in the harvested turfgrass clippings. Changes in soil bulk density, water retention, pH and the concentrations of nutrients, heavy metals and soluble salts were also measured during turfgrass growth. It was found that 10-20% CSS amendment was optimum for turfgrass growth while having negligible impacts on soil heavy metal and soluble salt contents. Results of this study can serve as a practical guide for field applications of CSS as a soil amendment for turf production.

MATERIALS AND METHODS

A sandy loam was used as the base soil. The sewage sludge was obtained from central Wastewater Treatment Plant (Ahvaz, Iran) and was composted in a CTB-1 automated fast composting system. Both the soil and the CSS produced were air dried and sieved to obtain the <2 mm fraction. The major chemical properties of the base soil and the CSS are listed in Table 1.

The experiment was set up at the Shahid Chamran University, located in the northwest of Ahvaz. All studies were conducted in a greenhouse with controlled temperature (25-30°C) and relative humidity (50-60%). Plastic bins of 25 cm in width and 34 cm in length were filled with 5.0 kg of soil, CSS, or their mixtures, respectively. The growth of turfgrass was compared in

Table 1: Major chemical properties of the base soil and the CSS used in this study

Substrate	Base soil	CSS
pH	8.04	6.86
Total organic content (g kg^{-1})	16.40	210.00
Total N (g kg^{-1})	0.82	11.00
Total P (g kg^{-1})	1.92	7.95
Nitrate and extractable ammonium (mg kg^{-1})	101.00	707.00
Extractable P (mg kg^{-1})	37.80	2174.00
Exchangeable K (mg kg^{-1})	43.00	593.00
Extractable Cu (mg kg^{-1})	2.44	7.73
Extractable Zn (mg kg^{-1})	0.73	79.10
Extractable Pb (mg kg^{-1})	2.42	9.11
Extractable Cd (μg kg^{-1})	86.50	242.00

eight substrates: base soil (CK), chemical fertilizer reference soil (NPK, base soil added with 3% N, 1.7% P_2O_5 and1% K_2O), 5% CSS/95% base soil (CSS5), 10% CSS/90% base soil (CSS10), 20% CSS/80% base soil (CSS20), 40% CSS/60% base soil (CSS40), 70% CSS/30% base soil (CSS70) and 100% CSS (CSS100). Each treatment has four replication.

The experiment was conducted from 28 February to 3 July 2005, with a mean daily sunshine duration of 10 h day. Seeds of (variety: Tifway) with a germination rate of 94.7% were planted at a seeding rate of 35 g m^2 in the plastic bins. The substrates were irrigated regularly with appropriate amounts of water after seeding. The seedling emergence date and the numbers of seedlings emerged were recorded. The turfgrasses were mowed three times (on 9 April, 19 May and 3 July 2005) during the study period, with one-third of the leaf blade cutoff. Clippings were collected and weighted to determine clipping yield as an indication of shoot growth. Contents of chlorophyll, nutrients (N, P and K) and heavy metals (Cu, Zn, Pb and Cd) in the clippings were also determined.

Physical and chemical properties, nutrient and heavy metal contents of the base soil, CSS and soils amended with different levels of CSS were determined according to the standard soil testing methods (Tavallali and Semnani, 2003). Bulk density was determined from the volume and mass of soil sample that had been dried at 105°C. Soil water content was determined by gravimetric method based on the weight loss of wet soil sample at 105°C. Soil pH and soluble salts were determined in a 1:1 suspension. Soil organic matter content was measured by the loss on ignition method with sample ashing at 550°C. The total nitrogen was measured with the Kjeldahl method based on the wet oxidation of organic matter and conversion of organic nitrogen to the ammonium form. Soil nitrate and extractable ammonium were measured by equilibrium extraction of soil for nitrate and ammonium with 2N KCl. Total phosphorus was determined by acid digestion of the soil sample using concentrated HNO_3 and $HClO_4$. Extractable phosphorus was measured by the Olsen method, which is based on alkaline extraction using 0.5N $NaHCO_3$. Exchangeable potassium was measured by extracting the soil sample with 1N NH_4CH_3COO (at pH 7.0). Nitrogen and phosphorous concentrations were quantitatively determined by UV-vis spectrophotometry, while those of potassium were determined by atomic absorption/emission spectrometry. Extractable zinc, copper, lead and cadmium were measured by extraction using DTPA solution (0.005 M DTPA, 0.1 M TEA and 0.01 M $CaCl_2$, pH 7.3) and inductively coupled plasma atomic emission spectrometry (Tavallali and Semnani, 2003).

Total nitrogen in the harvested turfgrass clippings was measured by the Kjeldahl method using H_2SO_4 digestion and UV-vis spectrophotometry. Total elements (including P, K, Zn, Cu, Pb and Cd) in the clippings were measured by HNO_3/H_2O_2 microwave digestion with quantitative determination by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Chlorophyll content of the clippings was measured using the standard method with 80% acetone extraction of homogenized leaf tissue followed by light absorbance measurement (Tavallali and Semnani, 2003).

Differences in terms of the weight, nutrient and heavy metal contents in clippings of Bermudagrass and the extractable heavy metal concentrations between the CSS-amended substrates and controls (base and reference soils) were determined by one-way ANOVA followed by the Tukey's Honestly Significant Difference (HSD) post hoc test (Zar, 1996). A p-value = 0.05 was considered significant for all statistical tests.

RESULTS AND DISCUSSION

Table 2 summarizes the dates and rates of Bermudagrass seedling emergence in different substrates and the fresh weights of clippings harvested. The seedling emergence dates are identical for the base and reference soils and soils containing up to 40% CSS. Seedling emergence was delayed by 2 days in the soils with 70 and 100% CSS, indicating inhibitory effect at high CSS contents. The highest seedling emergence rate occurred in the soil with 5% CSS and the seedling emergence rate showed a decreasing trend with increases in soil CSS content. Inhibition on seedling germination and emergence typically occurs at relatively high levels of compost amendment (Eklind *et al.*, 2001).

The soil with 5% CSS (CSS5) also produced the highest clipping yield (18.5 g) among the first harvests. Differences in the first harvest clipping yields from soils with 10 and 20% CSS (CSS10 and CSS20) and the reference soil were not significant, while the yield decreased significantly as the CSS content continued to increase. The second harvest clipping yields from soils with 5-20% CSS (CSS5, CSS10 and CSS20) were significantly higher than those from the rest of substrates. In the third harvest, the clipping yields of Bermudagrass grown in CSS5, CSS10 and CSS20 were significantly higher than the rest, with CSS20 produced the highest yield. These results indicate that Bermudagrass grew better in the soil with 5% CSS during the early stage, while the long-term growth was better in those with 10-20% CSS. This is attributed to the gradual depletion of nutrients, especially N in the soils amended with low levels of CSS during Bermudagrass andthis conclusion is supported by the changes in substrate N, P and K

Table 2: Dates and rates of Bermudagrass seedling emergence and the fresh weight of the harvested clippings

Substrate	Seedling emergence date (%)	Seedling emergence rate (%)	Fresh weight (g) of harvested clippings First (40 days growth)	Second (40 days growth)	Third (45 days growth)	Total
CK	4 March 2005	93.1	12.7±1.0c	11.8±0.8c	11.8±1.1cd	36.3±2.9b
NPK	4 March 2005	93.9	15.3±1.1b	14.7±1.0b	12.7±0.9c	42.7±3.0b
SS5	4 March 2005	94.2	18.5±1.2a	20.0±1.8a	15.3±1.4b	53.8±4.4a
SS10	4 March 2005	93.8	14.9±1.0b	18.7±1.2a	17.6±1.3ab	51.2±3.5a
SS20	4 March 2005	93.6	14.0±1.1bc	17.6±1.6a	18.3±1.2a	49.9±3.9a
SS40	4 March 2005	92.8	5.29±0.42d	8.41±0.82d	10.1±0.9d	23.8±2.1 c
SS70	6 March 2005	90.0	4.22±0.36d	4.08±0.26e	3.43±0.27e	11.7±0.9d
SS100	6 March 2005	88.1	3.64±0.26d	3.29±0.30e	2.65±0.26e	9.58±0.82d

Note: data within each column with the same letter do not differ significantly, according to Tukey's HSD test (p>0.05)

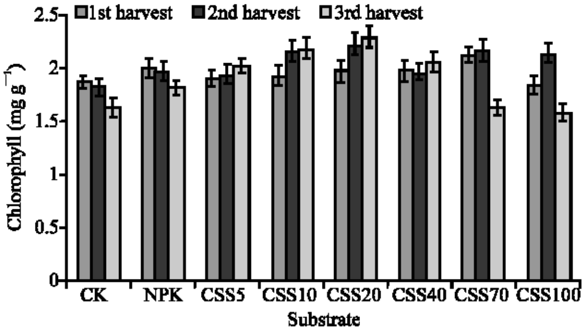

Fig. 1: Chlorophyll contents (mg g^{-1} fresh weight) in the harvested clippings of Bermudagrass grown in different substrates (error bars represent the standard errors)

contents during the growth period (Fig. 2). Substrates containing 40-100% CSS showed significant inhibition effect on Bermudagrass growth. In particular, many seedlings grown in CSS100 gradually withered and died during the study period. Chlorophyll is the molecule that performs photosynthesis and it is found in the chloroplasts of green plants. For Bermudagrass in this study, changes in chlorophyll content could occur as a result of nutrient deficiencies or exposure to environmental stress (e.g., heavy metals and soluble salts). Figure 1 shows the chlorophyll content in harvested clippings of Bermudagrass grown in different substrates. The soil with 70% CSS (CSS70) produced turfgrass that had the highest chlorophyll content (2.13 mg g^{-1} among the first harvests. A slightly increasing trend was also observed for chlorophyll contents as the CSS contents of the soil increased from 5 to 70%, which were all higher than that in the base soil. Chlorophyll contents of Bermudagrasses grown in soils with 20 and 40% CSS amendments and the reference soil were comparable (1.99-2.03 mg g^{-1}). For the second harvests, chlorophyll content was the highest in Bermudagrass grown in the soil with 20% CSS, with Bermudagrasses from CSS-amended soils all showed comparable or higher chlorophyll contents relative to those from the base and reference soils. The highest chlorophyll contents in the third harvests also occurred in Bermudagrasses grown in the soil with 20% CSS amendment (CSS20), while only Bermudagrasses grown in soils with 5-40% CSS amendments showed chlorophyll contents higher than that from the reference soil. Overall, chlorophyll contents of Bermudagrasses in the second harvests were higher than those in the first harvests, while the chlorophyll contents decreased in the third harvests from soils with high (≥40%) CSS contents. These results are indicative of fertilizer effect of CSS amendment at low levels on Bermudagrass growth, as well as environmental stress on Bermudagrass grown in soils with high (≥40%) CSS contents. Chlorophyll contents of Bermudagrass grown in the base and reference soils decreased over time, probably due to depletion of nutrients during growth. In contrast, chlorophyll contents in the Bermudagrass grown in soils with 5-20% CSS amendments increased continuously, indicating the advantage of CSS as a slow-release fertilizer.

N, P and K are all important nutrients for turfgrass and their supplies are critical for the quality of turf and the overall growth. Table 3 shows the nutrient contents in harvested clippings of Bermudagrass grown in different substrates. Bermudagrass grown in the CSS-amended substrates all had N, P and K contents higher or comparable to those grown in the base and reference soils and the contents of N, P and K in Bermudagrasses increased with the content of CSS in the substrates. It also appears that nitrogen contents in Bermudagrasses grown in the CSS-amended soils increased steadily over time, while nitrogen contents of Bermudagrasses from the base and reference soils peaked at the second harvest. These results consistently indicate that the CSS served as a long-term source of nitrogen in the soil. Phosphours and K contents in Bermudagrass grown in different substrates also showed that P and K could be quickly released from CSS during the early turfgrass growth stage, while slow-release fractions were also present that functioned as long-term nutrient sources. Potassiam contents of Bermudagrass in the third harvests were significantly lower compared to the rest of harvests in all substrates,

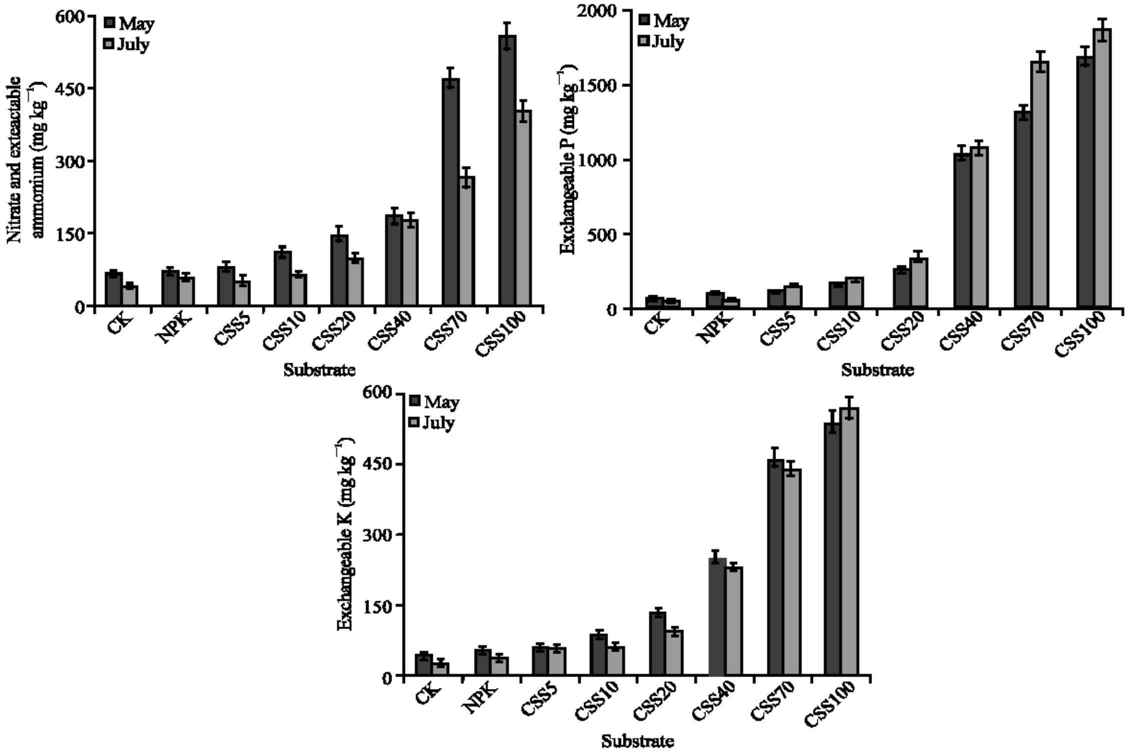

Fig. 2: Changes in substrate nutrient contents (with standard errors represented by the error bars) during Bermudagrass growth: (a) nitrate and extractable ammonium; (b) extractable phosphorous and (c) exchangeable potassium

Table 3: Nutrient contents in the harvested clippings of Bermudagrass grown in different substrates

	N (mg g^{-1})			P (mg g^{-1})			K (mg g^{-1})		
Substrate	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest
CK	15.6±0.2d	16.7±0.4c	16.0±0.6e	4.82±0.16d	4.59±0.15d	3.60±0.19d	19.9±1.0b	17.6±1.0c	10.8±0.8c
NPK	17.1±0.4c	17.4±0.4c	17.3±0.5d	5.86±0.16bc	5.67±0.17bc	4.00±0.27d	22.4±1.0ab	32.5±1.7b	15.2±0.7b
SS 5	16.2±0.3d	17.3±0.4c	20.6±0.6c	5.47±0.20c	5.38±0.17c	4.11±0.23cd	22.2±1.3ab	32.7±1.9b	15.3±1.0b
SS 10	16.5±0.3cd	18.6±0.4b	21.1±0.5c	5.90±0.15b	5.76±0.19bc	4.22±0.25cd	23.0±1.5ab	35.5±2.3ab	16.9±1.3b
SS 20	17.0±0.4cd	18.9±0.4b	21.9±0.6bc	6.24±0.19ab	5.96±0.23b	4.67±0.17c	23.2±1.6ab	37.1±1.7a	17.2±1.3ab
SS 40	17.1±0.4c	19.0±0.5b	22.5±0.5b	6.60±0.20a	6.06±0.25b	5.30±0.31b	23.8±1.9a	37.6±1.4a	18.0±1.0ab
SS 70	19.5±0.4b	19.4±0.5b	22.9±0.6b	6.00±0.16b	6.59±0.22a	6.01±0.28a	23.6±1.6a	38.7±1.7a	18.4±1.1ab
SS 100	20.4±0.5a	20.9±0.5a	24.6±0.6a	4.80±0.14d	6.79±0.25a	4.61±0.27c	23.9±1.6a	38.9±2.0a	19.6±1.4a

Note: data within each column with the same letter do not differ significantly, according to Tukey's HSD test ($p>0.05$)

probably because most K in the CSS was associated with the organic matter and present in the quick-release form. Therefore, addition of K fertilizer may still be necessary for long-term management of turfgrass grown in CSS-amended soils.

In general, there is a trend of increasing turf growth and quality as amended CSS content increased from 0 to 20%. Significant detrimental effects on Bermudagrass germination and growth occurred in substrates with CSS content ≥40%. Based on these results, we recommend amending CSS to turfgrass growth substrate at a rate of no more than 20%. The improvement in turfgrass growth and quality by CSS amendment is attributed to the amounts of nutrients that the compost provided to the turf (Angle *et al.*, 1981). Substantial amounts of plant-available N, extractable P and exchangeable K were present in the CSS (Table 1) andthey could be readily uptaken by Bermudagrass during growth. This is also supported by the high concentrations of N, P and K in the substrates during the study period (Fig. 2). The high nutrient contents in CSS and the reduced clipping yields and chlorophyll contents of Bermudagrass grown in substrates with high CSS contents (≥40%) suggest that chemicals that can cause environmental stress are also associated with the CSS, besides the nutrients.

The evaluation of heavy metal transfer from growth substrates to plants is important in order to avoid potential exposure hazards from contacting the turfgrass.

Table 4: Contents of Cu, Zn, Pb and Cd in the harvested clippings of Bermudagrass grown in different substrates

	Cu (mg kg^{-1})			Zn (mg kg^{-1})		
Substrate	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest
CK	27.0±1.4c	33.5±1.7b	32.1±2.3e	50.7±3.4d	64.2±3.6c	70.6±3.3b
NPK	27.9±1.7c	40.1±2.8a	41.6±1.9d	60.3±2.9c	66.6±3.8c	76.5±4.3b
SS 5	25.7±1.3c	26.7±1.8c	31.9±2.0e	63.7±3.4c	63.7±4.5c	78.2±4.9b
SS 10	26.5±1.0c	27.2±1.2c	43.9±2.4cd	78.4±3.8b	89.3±4.1b	107±7a
SS 20	29.0±1.7c	27.6±1.8c	49.3±3.1c	87.9±4.3b	99.6±4.9b	110±6a
SS 40	31.1±1.8bc	27.5±2.0c	58.7±2.9b	97.3±5.0ab	108±6ab	114±7a
SS 70	33.5±1.9b	28.1±1.9c	68.5±3.6a	97.8±6.1ab	117±6a	107±6a
SS 100	37.8±2.3a	29.1±1.9bc	71.5±3.9a	106±7a	107±7ab	102±5a
	Pb (mg kg^{-1})			Cd (mg kg^{-1})		
	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest
CK	3.71±0.22b	3.84±0.22c	4.49±0.25b	0.41±0.03b	0.83±0.06a	0.73±0.05a
NPK	4.32±0.30b	4.56±0.27c	4.99±0.37b	0.49±0.04a	0.79±0.07ab	0.70±0.05ab
SS 5	2.75±0.25c	7.66±0.41b	8.46±0.42a	0.30±0.03c	0.62±0.05b	0.59±0.02b
SS 10	3.80±0.22b	8.49±0.36ab	8.78±0.48a	0.31±0.02c	0.70±0.04ab	0.66±0.05ab
SS 20	3.76±0.24b	8.78±0.45a	8.95±0.56a	0.28±0.03c	0.67±0.05b	0.60±0.03ab
SS 40	4.18±0.19b	8.84±0.39a	9.08±0.46a	0.31±0.02c	0.75±0.06ab	0.62±0.05ab
SS 70	6.05±0.40a	9.24±0.49a	9.42±0.45a	0.32±0.03c	0.75±0.07ab	0.64±0.06ab
SS 100	5.64±0.23a	9.11±0.41a	9.20±0.44a	0.32±0.02c	0.77±0.05ab	0.66±0.05ab

Note: data within each column with the same letter do not differ significantly, according to Tukey's HSD test (P>0.05)

Table 5: Changes in physical and chemical properties of the substrates during Bermudagrass growth

			Soil pH			Organic content (mg kg^{-1})	
Substrate	Bulk density (g cm^{-3})	Soil water retention (%)	February	May	July	May	July
CK	1.68	24.1	8.04	8.08	7.97	25.9	21.7
NPK	1.67	24.0	-	-	-	25.0	20.3
SS5	1.59	25.7	7.97	7.74	7.58	29.6	27.8
SS10	1.50	29.9	7.74	7.68	7.43	35.2	32.6
SS20	1.46	32.2	7.55	7.31	7.24	48.8	44.8
SS40	1.37	39.5	7.29	7.12	6.92	73.6	67.6
SS70	1.32	-	6.94	6.89	6.80	114.0	110.0
SS100	1.24	-	6.86	6.75	6.53	176.0	159.0

Table 6: Changes in extractable heavy metal concentrations in different substrates during Bermudagrass growth

	Cu (mg kg^{-1})		Zn (mg kg^{-1})		Pb (mg kg^{-1})		Cd (µg kg^{-1})	
Substrate	May	July	May	July	May	July	May	July
CK	2.03±0.13e	1.98±0.11b	2.380.17e	1.55±0.09g	2.32±0.14de	1.96±0.10f	72.0±4.9e	53.5±2.9d
NPK	2.05±0.11d	1.99±0.09b	2.32±0.13f	1.68±0.11g	2.39±0.13de	2.11±0.13f	72.6±4.0e	56.7±3.1d
SS5	2.30±0.12cd	2.07±0.10b	6.75±0.47d	7.62±0.50f	1.98±0.08e	2.23±0.15ef	74.6±3.5de	57.6±4.0d
SS10	2.46±0.17c	1.93±0.14b	10.6±1.0d	14.2±0.7e	2.54±0.12d	2.78±0.13e	89.8±3.3d	68.5±3.5d
SS20	2.61±0.14c	1.91±0.11b	18.3±1.1c	20.4±1.0d	3.44±0.16c	3.62±0.22d	123±7c	84.1±4.9c
SS40	2.99±0.16b	2.03±0.13b	45.8±2.9b	39.5±2.1c	3.98±0.23b	5.10±0.30c	182±11b	110±6b
SS70	3.06±0.19ab	2.17±0.14b	47.1±2.9b	47.5±2.8b	5.72±0.38a	5.79±0.39b	181±10b	173±10a
SS100	3.36±0.20a	3.83±0.24a	60.1±2.8a	67.0±3.6a	5.31±0.31a	6.56±0.44a	273±13a	179±12a

Note: data within each column with the same letter do not differ significantly, according to Tukey's HSD test

Composts made from sewage sludge often have higher metal concentrations than those made from other sources (Landschoot, 1996) and Table 1 shows that the extractable heavy metal contents in the CSS are 3 to >100 times higher than those in the base soil. In general, the presence of CSS in the substrates resulted in increases in Zn, Cu and Pb contents of Bermudagrass (Table 4). Contents of these heavy metals in Bermudagrass also gradually increased with time, although in several cases, the metal contents were lower in the third harvest than in the second one. The translocation of Cu, Zn and Pb into Bermudagrass seemed to be a slow process, according to the gradual increases in heavy metal contents over time. Similar observations have also been made on absorption of heavy metals by broccoli plants (Perez-Murcia *et al*., 2006). Although the contents of Cu, Zn and Pb in Bermudagrass grown in CSS-amended substrates were generally higher than those in Bermudagrass from the base and reference soils, the concentration increases were less than 2.3-folds in all cases.

The increased uptakes of Cu, Pb and Cd contents in Bermudagrass grown in substrates amended with CSS can be attributed to the higher heavy metal contents in these substrates (Table 6) and metal transport facilitated by organic ligands (e.g., oxalate, citrate, acetate) produced during organic matter degradation (Meagher, 2000). It has been reported that heavy metal toxicity was enhanced gradually with increasing concentration of low molecular weight organic acids, reducing the chlorophyll content and biomass of Bermudagrass (Liao and Huang, 2002). Compared to the increases in extractable Cu (up to 1.9-folds), Zn (up to 43-folds), Pb (up to 3.3-folds) and Cd (up to 3.8-folds) in the CSS-amended soils (Table 6), these heavy metals did not significantly accumulate in Bermudagrass. It is noted that the presence of CSS actually reduced Cd content in clippings of Bermudagrass, while it has been reported that humic acid could reduce Cd uptake by Bermudagrass (Liao and Huang, 2002). Furthermore, absorption of Cd by Bermudagrass is restricted by the root. Studies have shown that the concentration of Cd was higher in roots than in shoots, indicating that the roots of Bermudagrass could prevent transport of Cd from roots to shoots and reduce Cd accumulation in the shoots (Liao and Huang, 2002; Jarvis and Jones, 1978).

The above observations indicate that the detrimental effects on Bermudagrass germination and growth associated with substrates having high (≥40) CSS contents were probably not caused by the presence of heavy metals. This conclusion is in agreement with the findings of previous studies. Sims (1990) found that heavy metals did not limit the growth of wheat (*Triticum aestivum* L.) plants in soils amended with cocomposted sewage sludge if adequate amounts of supplemental N fertilizers were applied. Manios *et al*. (2003) reported that heavy metals (Cd, Cu, Ni, Pb and Zn) in different compost materials did not affect the mean chlorophyll contents in *Typha latifolia* plants, which is indicative of no significant toxic action, although the metals accumulation (toxic effect) led to increase in chlorophyll hydrolysis (reduction in chl*a* to chl*b* ratio). Dolgen *et al*. (2004) also reported that application of sludge from an agro-industry (vegetable processing factory) did not significantly increase Ni, Pb, Cd and Mn contents of lettuce plants.

Table 5 summarizes the changes in basic properties of the substrates during Bermudagrass growth. The substrate bulk density decreased (5.4-26.2%) with increases in CSS content, due to the lower density of the CSS. Because of the high organic matter content of CSS, the amended substrates weighed much less compared to mineral-based soils. It is expected that sods produced from CSS amended soils weigh less and have lower shipping costs. Water retention of the substrates also improved with the CSS content, which is beneficial for turfgrass growth. pH of the substrates gradually decreased with increases in CSS content and the pH also decreased over time. These were attributed to the weak organic acids released from degradation of organic matters in the CSS as well as H^+ produced from mineralization of nitrogen in the organic matter (Habteselassie *et al*., 2006; Sims, 1990). Overall, soils with CSS amendments still had near neutral pH values (6.5-8.1), a range favorable for turfgrass root growth (Landschoot, 1996). Organic matter contents of the CSS-amended soils were much higher than the base and reference soils in May and July, indicating that large amounts of organic matters remained.

Figure 2 shows the changes in substrate nutrient contents during Bermudagrass growth. After 2 months of turfgrass growth, nitrate and extractable ammonium, extractable phosphorous and exchangeable potassium in CSS-amended soils were all significantly higher than those in the base and reference soils. Similar observations were also made on the contents of soil nutrients after the third harvest. Nitrate and extractable ammonium and exchangeable potassium contents in CSS-amended soils were lower in July than in May, while extractable phosphorous continued to increase. This was probably caused by the relatively higher phosphorous release rate compared to the uptake rate by turfgrass during the study period. Depending on the composition of the CSS, only a small fraction of the total phosphorous may be present in water-extractable form and considerable accumulation of phosphorous (50-95% increase) can take place in the soil (Krogstad *et al*., 2005). The amounts of N, P and K supplied by CSS increased proportionally with the quantity of CSS added. Based on the discussions in the previous sections, it appears that CSS amendment at ≤20% levels was sufficient to achieve desired turfgrass growth. Due to the high nutrient contents in CSS, over-amendment of the soil may result in continued N and P exaccumulation in the soil, which may possibly increase N and P runoff (Krogstad *et al*., 2005).

Anthropogenic metals (Cu, Zn, Pb and Cd) cause soil pollution when present at high levels and may have a toxic effect on plant growth. Table 6 shows the extractable Cu, Zn, Pb and Cd concentrations in different substrates during Bermudagrass growth. Higher heavy metal concentrations were observed in soils with higher CSS contents, consistent with CSS being the major source of heavy metals. The low molecular weight organic acids (e.g., oxalic acid, citric acid and acetic acid) produced during degradation of the organic matter in the CSS could function as chelating agents, which increase the fraction of heavy metals that can be extracted. Extractable Zn and Pb concentrations increased with time, while those of Cu and Pb were generally lower in July compared to in May. As insignificant amounts of heavy metals were uptaken into Bermudagrass during the growth (Table 4), the variations in extractable heavy metal concentrations might be caused by soil microorganism activity and soil pH changes. Standards on extractable heavy metals in soils have not been established in China. However, to minimize potential soil pollution by heavy metals, CSS should be added only to the levels sufficient for supporting turfgrass growth.

Soils amended with CSS are expected to have elevated soluble salt contents because relatively high concentrations of soluble salts are typically present in CSS (Eklind *et al*., 2001). Figure 3 shows the electrical conductivity of the substrates before seeding, during and after Bermudagrass growth. The data indicate that the soluble salt contents in CSS-amended soils increased with the CSS contents and that soluble salt contents in the soils amended with 20-100% CSS also increased over time. Measurements of the electrical conductivity of the top and bottom 2 cm layers of the substrates at the end of the experiment showed that the top layer contained much more soluble salts than the bulk and the bottom layer. This can be explained by the evaporation of soil solution near the surface layer and the leaching effect near the bottom layer. Comparison with the seedling emergence rate data suggests that substrates with electrical conductivity above ~2 mS cm^{-1} significantly inhibited the seedling emergence. Furthermore, direct correlation between seedling death and the appearance of recognizable salt layer on the substrate surface was observed in this study for 100% CSS. These findings agree with the observed correlation between increased salinity of substrates and the decrease of germination rate (Jarvis and Jones, 1978). The seedling death is primarily attributed to the presence of excessive soluble salts, which cause injury to turfgrass by reducing root water absorption, by toxicity, or by a combination of both (Landschoot, 1996). Therefore, the soluble salt contents in CSS also determine that it should only be added to soils at moderate levels to avoid detrimental effects on turf growth.

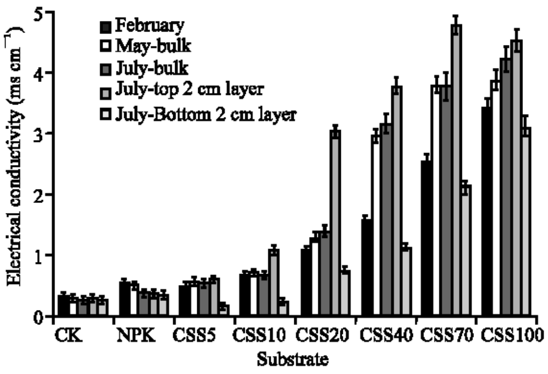

Fig. 3: Changes in soluble salt contents (with standard errors represented by the error bars) of different substrates as indicated by the electrical conductivity during Bermudagrass growth

CONCLUSIONS

Utilization of CSS as a soil amendment for turfgrass production not only reduces the raw material and nutrient requirements, but also alleviates the waste disposal demand. Results of this study show that CSS at≤20% levels can be used as a slow-release fertilizer for turfgrass production. Bermudagrass grown in soils with 5-20% CSS had higher clipping yields and higher nutrient contents, compared to the control. On the other hand CSS increased the levels of heavy metals and soluble salts in the amended soil, which increased the potential of soil pollution and had inhibition effect on turfgrass growth. Based on these observations, we recommend amending soils with 10-20% CSS for optimum turfgrass growth. CSS amendment at these levels can greatly improve the soil nutrient supply without significantly affecting its heavy metal and soluble salt contents. The high soluble salts content in CSS is a major concern for its application as a soil amendment. In practical applications, it may be necessary to remove the soluble salts from CSS (e.g., by rinsing with water) before amending to soils. Both economical and environmental benefits can be obtained by applying CSS as a soil amendment and it is a practical way to turn sewage sludge into valuable resources for the turf industry.

REFERENCES

Angle, J.S., J.R. Hall and D.C. Wolf, 1981. Turfgrass growth aided by sludge compost. Biocycle, 2: 40-43.

Angle, J.S., 1994. Sewage Sludge Compost for Establishment and Maintenance of Turfgrass. In: Handbook of Residue Integrated Pest Management for Turf and Ornamentals. Leslie, A.R. (Ed.), Lewis Publisher, Boca Raton, FL, pp: 45-52.

Bilgili, U. and E. Acikgoz, 2005. Year-round nitrogen fertilization effects on growth and quality of sports turf mixtures. J. Plant Nutr., 28: 299-307.

Brady, N.C. and R.R. Weil, 1999. The Nature and Properties of Soils. 12th Edn., Prentice Hall, Upper Saddle River, N.J.

Cisar, J.L. and G.H. Snyder, 1992. Sod production on a solid-waste compost over plastic. Hortic. Sci., 27: 219-222.

Dolgen, D., M.N. Alpaslan and N. Delen, 2004. Use of an agro-industry treatment plant sludge on iceberg lettuce growth. Ecol. Eng., 23: 117-125.

Eghball, B. and J.E. Gilley, 1999. Phosphorus and nitrogen in run-off following beef cattle manure or compost application. J. Environ. Qual., 28: 1201-1210.

Eklind, Y., B. Ramert and M. Wivstad, 2001. Evaluation of growing media containing farmyard manure compost, household waste compost or chicken manure for the propagation of lettuce (*Lactuca sativa* L.) transplants. Biol. Agric. Hortic., 19: 157-181.

Garling, D.C., J.W. Rimelspach and M.J. Boehm, 1999. Impact of compost topdressings and fungicide program on dollar spot severity. Biol. Cult. Tests Contr. Plant Dis., 14: 134.

Garling, D.C. and M.J. Boehm, 2001. Temporal effects of compost and fertilizer applications on nitrogen fertility of golf course turfgrass. Agron. J., 93: 548-555.

Giusquiani, P.L., M. Pagliai, G. Gigliotto, D. Businelli and A. Benetti, 1995. Urban waste compost: Effects on physical, chemical and biochemical soil properties. J. Environ. Qual., 24: 175-182.

Habteselassie, M.Y., J.M. Stark, B.E. Miller, S.G. Thacker and J.M. Norton, 2006. Gross nitrogen transformations in an agricultural soil after repeated dairy-waste application. Soil Sci. Soc. Am. J., 70: 1338-1348.

He, X., S.J. Traina and T.J. Logan, 1992. Chemical properties of municipal solid waste composts. J. Environ. Qual., 21: 318-329.

Jarvis, S.C. and L.H.P. Jones, 1978. Uptake and transport of cadmium by Bermudagrass from flowing solution culture with a constant concentration of cadmium. Plant Soil, 49: 333-342.

Kizilkaya, R., 2004. Cu and Zn accumulation in earthworm *Lumbricus terrestris* L. in sewage sludge amended soil and fractions of Cu and Zn in casts and surrounding soil. Ecol. Eng., 22: 141-151.

Krogstad, T., T.A. Sogn, A. Asdal and A. Sæbø, 2005. Influence of chemically and biologically stabilized sewage sludge on plant-available phosphorous in soil. Ecol. Eng., 25: 51-60.

Landschoot, P.J. and D.V. Waddington, 1987. Response of turfgrass to various nitrogen fertilizers. Soil Sci. Soc. Am. J., 51: 225-230.

Landschoot, P.J. and A.S. McNitt, 1994. Improving turf with compost. Biocycle, 35: 54-57.

Landschoot, P., 1996. Using Composts to Improve Turf Performance. Publications Distribution Center, Pennsylvania State University Cooperative Extension, University Park, PA.

Landschoot, P.J. and A.S. McNitt, 1997. Effect of nitrogen fertilizers on suppression of dollar spot disease of *Agrostis stolonifera* L. J. Int. Turfgrass Soc. Res., 8: 905-911.

Lee, D.K. and P.E. Rieke, 1993. Soil cultivation effects on establishment of *Poa pratensis* L. sod. Int. Turfgrass Soc. Res. J., 7: 437-443.

Liao, M. and C. Huang, 2002. Effects of organic acids on the toxicity of cadmium during Bermudagrass growth. Ying Yong Sheng Tai Xue Bao, 13: 109-112.

Liu, L.X., T. Hsiang, K. Carey and J.L. Eggens, 1995. Microbial populations and suppression of dollar spot disease in creeping bentgrass with inorganic and organic amendments. Plant Dis., 79: 144-147.

Logan, T.J. and B.J. Harrison, 1995. Physical characteristics of alkaline stabilized sewage sludge (N-Viro soil) and their effects on soil physical properties. J. Environ. Qual., 24: 153-164.

Loschinkohl, C. and M.J. Boehm, 2001. Composted biosolids incorporation improves turfgrass establishment on disturbed urban soil and reduces leaf rust severity. Hortic. Sci., 36: 790-794.

Manios, T., E.I. Stentiford and P.A. Millner, 2003. The effect of heavy metals accumulation on the chlorophyll concentration of *Typha latifolia* plants, growing in a substrate containing sewage sludge compost and watered with metaliferus water. Ecol. Eng., 20: 65-74.

Meagher, R.B., 2000. Phytoremediation of toxic elemental and organic pollutants. Curr. Opin. Plant Biol., 3: 153-162.

Nelson, E.B. and C.M. Craft, 1992. Introduction and establishment of strains of *Enterobacter cloacae* in golf course turf for the biological control of dollar spot. Plant Dis., 75: 510-514.

Norrie, J. and A. Gosselin, 1996. Paper sludge amendments for turfgrass. HortScience, 31: 957-960.

Pagliai, M. and L.A. Antisari, 1993. Influence of waste organic matter on soil micro- and macrostructure. Bioresour. Technol., 43: 205-215.

Parkinson, R., P. Gibbs, S. Burchett and T. Misselbrook, 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresour. Technol., 91: 171-178.

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. Bioresour. Technol., 97: 123-130.

Schumann, G.L., H. Soares, C.M. Holden and M.S. Switzenbaum, 1993. Relationship of traditional parameters of compost stability to turfgrass quality. Environ. Technol., 14: 257-263.

Sims, J.T., 1990. Nitrogen mineralization and elemental availability in soils amended with composted sewage sludge. J. Environ. Qual., 19: 669-675.

Tavallali, H. and A. Semnani, 2003. Methods of Analysis of Soils, Plants, Water and Fertilizer. Shahid Chamran University Press, Ahvaz, Iran.

Zar, J.H., 1996. Biostatistical Analysis 3rd Edn., Prentice Hall, Upper Saddle River, NJ.