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Effects of Wastewater Sludge Topdressing on Color, Quality, and Clipping Yield of a Turfgrass Mixture

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***Abstract*. The objectives of the present study were to determine the effects of the rate and timing of the application of sun-dried wastewater sludge from a food processing company's wastewater system on turfgrass growth and quality. The results were compared with those obtained with ammonium nitrate, and changes in the concentration of heavy metals and the presence of fecal coliform in turf soils after sun-dried wastewater sludge application were determined. The rate and the timing of sun-dried wastewater sludge and ammonium nitrate applications affected the turf color, quality, and clipping yield. Monthly fertilization resulted in a more uniform color and turf quality than infrequent spring and fall fertilization. Compared with the background values of base soils, heavy metals did not accumulate in sun-dried wastewater sludge-amended soils over the test period. Fecal coliform was not detected in sludge-amended soil samples, indicating that bacteria regrowth did not occur during the study period.**

Wastewater sludge contains high levels of organic matter and significant amounts of essential nutrients and trace elements for plant growth. Moreover, sludge can be considered a slow-release fertilizer as a result of its high concentration of organic nitrogen (N) (Davis, 1989; Kocaer et al., 2003). Plant-available nutrients such as N and phosphorous (P) in wastewater sludge could be used as a replacement for conventional fertilizers in agricultural production (Casado-Vela et al., 2006; Moreda et al., 1998). Therefore, wastewater sludge is recycled for agricultural purposes in many countries.

Wastewater sludge is rich in organic compounds and several plant nutrients. However, the reuse of sludge must be performed under conditions that limit the risks associated with pathogenic microorganisms present in the sludge. Sludge may contain pathogenic bacteria, viruses, and protozoa along with other parasitic helminths, which are hazardous to the health of humans, animals, and plants (Pescod, 1992). The reuse of agricultural sludge is only acceptable if the sanitary quality is guaranteed and public concern is limited. Because the presence of fecal coliforms in sludge directly relates to fecal contamination and the implied threat of the presence of enteric disease agents, limitations for fecal coliform bacteria are included in EU and U.S. sludge directives. To demonstrate that a given sludge meets U.S. Environmental Protection Agency (USEPA) Class B pathogen requirements, the density of fecal coliform bacteria from at least seven samples of sun-dried wastewater sludge (SDS) must be determined, and the geometric mean of the fecal coliform density must not exceed 2 million colony-forming-unit (CFU) or most probable number (MPN) per (dry weight) gram of total solids (USEPA, 2003).

The results of several studies indicated that land application of untreated sludge introduces large amounts of bacteria to leachates and soil (Kocaer et al., 2004). Moreover, heavy or toxic metals in the sludge threaten crop yields and long-term soil quality (Gardiner et al., 1995). For instance, some plants accumulate high concentrations of heavy metals (Singh and Agrawal, 2007). Therefore, these metals restrict the use of sludge for agricultural purposes (Dai et al., 2007; Udom et al., 2004).

Despite the considerable reduction in the levels of microbial organisms during the sludge treatment process (such as air drying and pasteurization), certain microbes may regrow in the sludge after the treatment is complete (Alkan et al., 2007). After the drying process, the regrowth risk is especially high, and nutrients in dried sludge are likely to enhance the regrowth of bacteria under certain conditions. Gibbs et al. (1997) suggested that the repopulation of fecal coliform bacteria occurred in soil amended with sludge after rainfall.

Few studies on the application of sludge as a soil amendment for turfgrass production have been conducted. Nevertheless, the results of a previous study demonstrated that turf quality increases with an increase in the timing and rate of composted sludge amendments during sod establishment (Angle et al., 1981). The observed increase in turfgrass quality was attributed to the presence of sufficient amounts of available nutrients in sewage sludges. The color of turfgrass produced from composted-sewage sludge amendments was comparable to that of turfgrass fertilized with ammonium nitrate (Angle, 1994; Markham, 1998). Moreover, if turfgrass receives adequate supplemental N, P, and potassium (K), deinked and primary-paper sludges can be effectively used as soil amendments to pure kentucky bluegrass (*Poa pratensis* L.) and kentucky bluegrass–perennial ryegrass (*Lolium perenne* L.) mixtures (Norrie and Gosselin, 1996). In greenhouse studies, the addition of 10% to 20% composted sewage sludge to plastic bins greatly improved the soil nutrient supply and turfgrass growth without significantly affecting soil heavy metal and soluble salt concentrations (Cheng et al., 2007). In South Africa, sludge obtained from a municipal water treatment plant was applied at a rate of 0, 8, 33, 67, and 100 $\text{mg}\cdot\text{ha}^{-1}$ of oven dry sludge in sod production of kikuyu (*Pennisetum clandestinum* Hochst. ex Chiov.). The results indicated that the sludge applications significantly increased the turfgrass establishment rate and color (Tesfamariam et al., 2009).

The objectives of the present study were to 1) determine the effects of the rate and timing of SDS applications on turfgrass growth and quality and to 2) measure the change in the concentration of heavy metals [lead (Pb), cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn), and mercury (Hg)], total N, nitrate, and ammonium N concentrations, available P, exchangeable K, soil pH, organic carbon, electrical conductivity (EC), and *Escherichia coli* count in turf soils after SDS application.

Material and Methods

The study was conducted on experimental turfgrass plots at the Uludag University Agricultural Faculty in Bursa, Turkey (lat. 40°15′ N, long. 29°01′ E, 70 m above sea level), between 2006 and 2009. The experimental area was located in the transitional zone and possessed a Mediterranean-type climate. The long-term average temperature was 14.6 °C, the average relative humidity was 69%, and annual precipitation was 699 mm in the region (Table 1). Temperature, rainfall, and relative humidity values during growing seasons

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Table 1. Monthly precipitation, mean air temperature, and relative humidity in 2007–2008 and 2008–2009 growing seasons and long-term (1929–2001) periods in Bursa.

	Temperature (°C)			Relative humidity (%)			Precipitation (mm)		
Months	2007–2008	2008–2009	Long-term	2007–2008	2008–2009	Long-term	2007–2008	2008–2009	Long-term
March	6.7	12.0	8.3	72	70	70.2	56.6	118.5	69.8
April	7.1	15.3	13.0	63	65	70.3	34.4	38.4	62.9
May	9.7	18.1	17.6	62	64	69.5	31.8	22.1	50.0
June	11.5	23.7	22.1	57	59	62.9	46.6	28.8	30.4
July	19.9	25.0	24.5	52	55	58.1	13.6	0.2	24.0
August	24.4	26.3	24.1	54	56	60.5	1.0	0.0	18.9
September	26.1	20.3	20.1	60	62	66.4	3.2	132.2	40.1
October	26.5	15.8	15.6	76	78	72.8	95.5	36.8	60.4
November	20.9	12.1	11.2	77	79	75.6	139.6	65.2	76.3
December	16.5	7.6	7.6	79	77	74.2	158.5	93.9	99.9
January	3.0	6.4	5.3	73	76	74.1	56.9	116.6	88.8
February	5.3	7.4	6.2	74	79	73.4	46.1	156.6	77.5
Average	14.8	15.8	14.6	66.7	68.3	69.0	—	—	—
Total	—	—	—	—	—	—	683.8	809.3	699.0

(March to February) are also shown in the table. Weather conditions differed slightly across growing seasons. Relative humidity of the 2007–2008 growing season was slightly lower (2%) than the long-term average. Average temperature of the 2008–2009 growing season was 1 °C above that of the long-term average. The 2008–2009 growing season can be characterized as wet with a total of 809.3 mm precipitation. Particularly, September received 110 mm more precipitation than normal.

According to soil analysis, the upper 20 cm of the soil was considered a sandy loam and was rich in K (112 mg K/kg or 250 kg K/ha). Moderate available P levels (18.4 mg·kg^{-1} or 41 kg P/ha) were observed, and the pH of the soil was 8.3 (Table 2).

Table 2. General characteristics of soil before amendment, and sun-dried sludge (SDS).

Parameters (on a dry matter basis)	Soil	SDS
pH (1:2.5, soil:water and 1:10, sludge:water)	8.3	6.3
Electrical conductivity (μmhos/cm)	134	1910
Total N (mg·kg^{-1})	1088	25800
Ammonium-N (mg·kg^{-1})	31.6	622
Nitrate-N (mg·kg^{-1})	18.1	27.6
Total P (mg·kg^{-1})	703	7318
Available P (mg·kg^{-1})	18.4	628
Organic C (%)	1.2	22.3
C/N (%)	10.9	8.6
K$^+$ (free + exchangeable) (mg·kg^{-1})	112	1812

N = nitrogen; P = phosphorus; C = carbon; K = potassium.

Table 3. Dry matter percentages and fecal coliform numbers of the raw and sun dried sludge and USEPA Standards.

			USEPA standards	
	Raw sludge	Sun-dried sludge	Class A	Class B
Dry matter (%)	16.5	93.80	—	—
Fecal coliform (MPN/g)	6.94×10^6	5.60×10^1	1×10^3	2×10^6

MPN = most probable number.

Wastewater sludge samples were collected from the wastewater treatment system of Penguen Food Company, Bursa, Turkey. The domestic and industrial wastewaters of the canning plant are treated together with activated sludge. Raw sludge was sun-dried for several days on concrete during hot summer days to achieve microbial stabilization. Sun-dried sludge was ground with a laboratory mill, and the particle size was reduced to less than 3 mm to obtain a uniform distribution on the surface of the plots. The major chemical and biological properties of the SDS used in the present study are summarized in Tables 2 and 3.

The soil was tilled, leveled, and rolled during the summer months. Before seeding, 20 g of P/m^2 and 10 g of K/m^2 were incorporated into the seedbed. In the field trial, treatments were arranged in a split-split plot design with three replications. The main plots were differentiated according to the application time, and the subplots were separated according to the N source. Lastly, the N rate was grouped into sub-subplots, which possessed dimensions of 1 × 2 = 2 m^{-2}. The seeding rate was set to 40 g·m^{-2}. The turf mixture was based on the seed weight of 50% perennial ryegrass (*Lolium perenne* L., cv. Esquire), 30% kentucky bluegrass (*Poa pratensis* L., cv. Conni), 10% Chewings fescue (*Festuca rubra* spp. *commutata* Gaud., cv. Juliska), and 10% creeping red fescue (*Festuca rubra* spp. *rubra* L., cv. Diego) and was established on 17 Oct. 2006. Seeds were broadcast and topdressed with a mixture of soil and peat and were irrigated as necessary to keep the soil surface moist until complete seedling emergence. Irrigation was applied regularly through a rotary sprinkler system to maintain a moist surface.

Nitrogen from SDS (2.58% N) or AN (33% N) was applied at four different application times, including monthly (M), spring + fall (S+F), spring only (S), and fall only (F). In addition, the following N application rates were evaluated: M: 2.5, 5.0, and 7.5 g·m^{-2}; S+F: 15 + 15, 30 + 30, and 45 + 45 g·m^{-2}; S or F: 30, 60, and 90 g·m^{-2}. In total, 30, 60, and 90 g·m^{-2} of N were applied yearly. Nitrogen was not applied to the control (control) plots.

The first fertilizer treatment was conducted in the middle of Mar. 2007, 5 months after sowing, and treatment was continued for 24 months. Plots were mowed with a rear-bagging rotary mower at 4 cm when the plants reached a height 6 to 8 cm. At each clipping date, a 0.5 m × 1.0-m strip was cut through the center of each plot, dried at 70 °C for 24 h in an oven, and weighed. Throughout the course of the study, the clippings were collected from six cuttings in the spring, five cuttings in the summer, four cuttings in the fall, and zero cuttings in the winter for a total of 15 cuttings.

During each growing season, visual turfgrass color ratings were obtained on each clipping date before mowing. A scale of 1 to 9 was used, where 1 = completely yellow and 9 = dark green. Based on the color, density, and uniformity of the grass, the turf quality was rated at each clipping date throughout the experiment (1 = poorest; 9 = excellent). In the present study, a rating of 6.0 or higher indicated that the quality of the grass was minimally acceptable. Typically, color and quality ratings were obtained on each clipping date; however, limited top growth was observed between December and February as a result of low temperatures. Thus, a cutting was not performed in the winter of 2007–2008 or 2008–2009. As a result, the color and quality ratings were obtained monthly during the winter to determine the effect of winter fertilization on turf growth and quality. Overall, a total of 24 color and quality ratings were obtained throughout the study.

Chemical analysis. The EC and pH of the soil (1:2.5 w/v soil: water) and sludge were measured (a 1:10 w/v sludge:water ratio was selected because the sludge was highly water absorbent) with a conductivity meter and a pH meter, respectively (McLean, 1982; Rhoades, 1982). The total N concentration was measured according to the Kjeldahl method (Bremner and Mulvaney, 1982), and nitrate- and ammonium-N concentrations were determined by steam distillation with MgO and Devarda alloy (Keeney and Nelson, 1982) after 2 M KCl extraction.

A 0.5 N $NaHCO_3$ solution was used to extract available P, and nitric acid–sulfuric acid digestions were performed to determine the total P content. The ascorbic acid method (APHA, AWWA, WEF, 1998) was used to determine the amount of PO_4^{-3}-P in the extracts. The organic carbon concentration was determined by potassium dichromate oxidation and spectrophotometric measurement at 590 nm (Nelson and Sommers, 1982).

A 1 N ammonium acetate solution was used to extract K^+ (free and exchangeable forms) from soil and sludge samples (Thomas, 1982), and the K^+ concentration of the extracts was determined by flame photometry (APHA, AWWA, WEF, 1998).

Heavy metal analysis. Original soil samples were collected before each treatment. At the end of the study, soil samples were collected in duplicate from each plot with a 5-cm auger, and samples treated with the same SDS dose were combined. Heavy metal analysis of the pooled soil samples was conducted in triplicate (TUBITAK, Bursa Test and Analysis Laboratory, Bursa, Turkey). The Pb, Cd, Cu, Ni, Zn, and Hg contents of soil and SDS samples were analyzed with an energy-dispersive X-ray fluorescence spectrometer (Spectro X-Laboratory 2000; Spectro Analytical Instruments) equipped with a 300-W Pd end window X-ray tube, a liquid N-cooled Si(Li) detector (less than 150 eV Mn K_{α}), and three targets, including molybdenum as the secondary target and Al_2O_3 and high-oriented pyrolytic graphite as the polarization targets.

Coliform counts analysis. Fecal coliform counts were performed in accordance with the most probable number method (APHA, AWWA, WEF, 1998), and brilliant green bile broth was used as a growth medium. Inoculated tubes were incubated at 44.5 ± 0.2 °C for 24 ± 2 h. The results were obtained as MPN per 100 mL and were converted to MPN per gram of dry matter.

Statistical analysis. All data across individual sampling dates were combined for the spring, summer, fall, and winter seasons of both years and were subjected to an analysis of variance using MINITAB (Minitab, Inc. USA, Minitab Release, 12.1, University of Texas, Austin, TX). When main or interaction effects were significant ($P < 0.05$), the means were separated using Fisher's least significant difference test at the 0.05 level.

Results and Discussion

The SDS was slightly acidic (pH 6.3), and the EC of the sludge was 1910 μmhos/cm (Table 2). Thus, the SDS was relatively saline, especially as a 1:10 extract. The total N content of the SDS was 25,800 $mg \cdot kg^{-1}$ (2.58%), indicating that the material could be used as an N fertilizer. The sludge contained relatively low extractable quantities of mineral N compared with the total N content (622 and 27.6 $mg \cdot kg^{-1}$ ammonium-N and nitrate-N, respectively). Land applications of SDS provided 7318 and 628 $mg \cdot kg^{-1}$ total and available P, respectively. The sludge contained a high organic carbon (C) concentration (22.3%) and could provide organic matter to soil if high rates are applied. The C:N ratio of SDS was 8.6, which is favorable for N mineralization. The soluble K^+ content and the other variables were in the range of the expected values for wastewater sludges (McFarland, 2000; Tchobanoglous and Burton, 1991). The density of fecal coliform bacteria in the SDS (56 MPN/g) was well below the Class B pathogen limit of 2 million CFU or MPN per (dry weight) gram of total solids (USEPA, 2003) (Table 3).

The seasons (SE), application time (AT), nitrogen sources (NS), nitrogen rate (NR), and their two-way and three-way interactions had a significant effect on turf color, quality, and clipping yields with the exception of the SE × NS × NR interaction (Table 4).

The N sources × N rate interactions clearly showed that color, quality ratings, and clipping yield significantly increased with increasing N rate in both AN and SDS applications (Table 5). Furthermore, no statistically significant differences were observed between AN and SDS applications in all N application rates, except at the 7.5 $g \cdot m^{-2}$ N rate.

The application times × N source × N rates interactions clearly showed that color and quality ratings increased with increasing N rates in all application times of AN and SDS (Table 6). The 7.5 $g \cdot m^{-2}$ N rate of both AN and SDS had higher turf color and quality ratings than the other N rates in all application times. The highest turf color ratings were obtained from the 7.5 $g \cdot m^{-2}$ N rate in M application time for SDS (8.1) and AN (8.0). Spring application time of AN presented significantly lower color and quality ratings than M and S+F applications in high N rates. Control plots had the lowest color (4.0) and quality ratings (3.7) in all applications. In contrast, the clipping yield was highly variable and was dependent on the N rate. Very little topgrowth was observed in control plots in all application times. The control plots averaged only 6.2 $g \cdot m^{-2}$ of clipping yield. Plots treated with the 5 and 7.5 $g \cdot m^{-2}$ N rates produced significantly higher clipping yields than 2.5 $g \cdot m^{-2}$. At N rates of 2.5, 5.0, and 7.5 $g \cdot m^{-2}$ N, AN-treated plots produced 126.8, 199.2, and 255.8 $g \cdot m^{-2}$ yearly clipping yields, regardless of application times. The corresponding yields were 86.0, 173.4, and 243.0 $g \cdot m^{-2}$ for SDS. Spring and S+F applications of AN produced the highest clipping yield, and the M application produced the greatest clipping yield for SDS. However, F application produced the highest clipping yield with either AN or SDS.

Table 4. Results of variance analysis for turf color, turf quality, and clipping yields under seasons (SE), different nitrogen sources (NS), application time (AT), and nitrogen rates (NR) across 2 years (2007–2008 and 2008–2009 growing periods).

Source	Color	Quality	Clipping yield
SE	**	**	**
AT	**	**	**
NS	NS	NS	**
NR	**	**	**
SE × AT	**	**	**
SE × NS	**	**	**
SE × NR	**	**	**
AT × NS	**	**	**
AT × NR	**	**	**
NS × NR	**	**	**
AT × NS × NR	**	**	**
SE × AT × NS	**	**	*
SE × AT × NR	**	**	**
SE × NS × NR	NS	NS	NS
SE × AT × NS × NR	NS	NS	NS

*,**, NS = Significant at $P = 0.05$ and 0.01, and nonsignificant ($P > 0.05$), respectively.

Season × application time × N source interactions indicated that color and quality ratings and clipping yield were highly variable within a season and dependent on the application time and N sources (Table 7). In the spring season, heavy S and S+F applications of AN had significantly higher color and quality ratings than the other application times. However, the response was not maintained during the following seasons, and the color and quality ratings decreased gradually. Split applications (M and S+F applications) of AN, and particularly SDS, presented more uniform turf color and quality ratings throughout the course of the experiment than the other application times. Spring and F applications with either N source had high color and quality ratings shortly after application; however, the color and quality rating decreased more rapidly than that of M and S+F applications in the following seasons. Spring application of both N sources had the lowest color and quality ratings in fall months. Fall-fertilized plots presented lower color and quality ratings in the spring and summer. After F fertilization, color and quality ratings increased significantly in fall and winter.

The clipping yield was highly variable and was dependent on the seasons, application times, and N sources. The control plots produced almost no topgrowth in winter regardless of the N source. Plots treated according to the S and S+F fertilization regimes of AN

Table 5. Turf color and quality ratings (1 to 9) and clipping yields ($g \cdot m^{-2}$) of a turf mixture at different nitrogen sources and nitrogen rates across 2 years (2007–2008 and 2008–2009 growing periods).

Nitrogen sources	Nitrogen rates ($g \cdot m^{-2}$) 0.0	2.5	5.5	7.5
		Color		
AN[z]	4.0 d[y]	6.3 c	7.0 b	7.4 a
SDS	3.9 d	6.3 c	7.0 b	7.5 a
		Quality		
AN	3.7 d	6.3 c	6.8 b	7.0 a
SDS	3.7 d	6.1 c	6.9 b	7.2 a
		Clipping yield		
AN	6.2 d	126.8 c	199.2 b	255.8 a
SDS	6.4 d	172.0 c	173.2 b	243.0 a

[z] AN = ammonium nitrate; SDS = sun-dried sludge.

[y] Mean values within each nitrogen source followed by the same letter are not significantly different at 0.05 level using the least significant difference test.

produced significantly higher clipping yields than other AN applications and all SDS applications in spring. Little topgrowth was observed in F-fertilized plots in the spring and summer and provided the lowest yield with either N source. The M application produced the highest yield for SDS in summer. However, in the fall season, S+F and F applications produced the highest clipping yield with either AN or SDS (Table 7).

In all of the seasons and in all application times, as the N rate increased from 0 to 7.5 g·m^{-2} N, the color and quality ratings increased (Table 8). However, the effect of the application times on the color and turf quality ratings varied according to the season. In the spring, 7.5 g·m^{-2} of S+F and 5.0 and 7.5 g·m^{-2} N of S fertilization regimes produced significantly higher color and quality ratings. Superior color and quality ratings were obtained in F and S+F-fertilized plots in fall when the rates of 5.0 and 7.5 were applied. Significant differences in the color and quality of the turfgrass were not observed between the 5.0 and 7.5 g·m^{-2} N rates in F and S+F fertilization regimes. In this study, the control plots produced low clipping yields in all seasons and application times. In control plots, an average clipping yields of 21.2, 3.4, 0.6, and 0.0 g·m^{-2} were obtained in spring, summer, fall, and winter seasons, respectively. Except in the winter, the clipping yield increased with an increase in the N rate in all of the seasons, and the maximum yields were obtained at an N rate of 7.5 g·m^{-2}. In spring, N fertilization yielded 220.2, 259.0, and 463.0 g·m^{-2} clipping yield when N rates of 2.5, 5.0, and 7.5 g·m^{-2} N were applied, respectively, regardless of N sources and application times. A similar pattern was also observed in summer and fall seasons.

Previous studies (Bilgili and Acikgoz, 2005; Wehner et al., 1988) indicated that turf color and quality are closely associated with N fertility. Namely, the color and quality ratings of turf mixtures and clipping yields increased with an increase in the N rate, which is in close agreement with the results of Hope (1978) and Spangenberg et al. (1986). In addition, previous studies also suggest that frequent, relatively low N applications (three to five applications during the year) are preferable to high-rate, infrequent N applications for the production of uniform turf quality. In our previous studies, monthly and bimonthly N applications produced more uniform color and quality ratings in different turf mixtures than single spring or fall N applications (Bilgili and Acikgoz 2005; Oral and Acikgoz, 2001). Compared with unfertilized plots and S applications, S+F, and F applications of SDS and AN resulted in higher color and quality ratings in the fall and winter as a result of superior fall and winter color retention. These findings are in accordance with the results obtained from several researchers in maritime or transitional regions (Ledeboer and Skogley, 1973; Wehner et al., 1988).

The results of the present study suggested that SDS can be used as an N fertilizer to produce high-quality turfgrass that is equivalent to those obtained from a synthetic soluble N source. This conclusion is in agreement with the results of previous studies (Loschinkohl and Boehm, 2001; Norrie and Gosselin, 1996; Schumann et al., 1993), which suggests that amendments with different kinds of organic composts and sludges can enhance turfgrass establishment, color, and quality.

The proportion of ammonium-N and nitrate-N to the total N of SDS was relatively low compared with chemical N fertilizers. However, hydrolyzable N constituted 91% of the total N content of the SDS used in the present study (Topac et al., 2008). Temperature, soil moisture, soil properties, and manure characteristics affect the release of nutrients in organic manures (Eghball et al., 2002). Apparently, hydrolyzable N in the SDS was easily and rapidly mineralized as a result of the low C:N ratio (8.6:1), and mineralized N was used by the turfgrass to produce quality equivalent to AN in most seasons.

In general, sludges possess high concentrations of metals (Dai et al., 2007; Udom et al., 2004). In Table 9, the maximum allowable heavy metal concentration of soils and sludge are presented along with the mean concentration of seven heavy metals in the surface soil (0 to 20 cm) of the experimental plots at the end of the study. Total Pb, Cd, Cu, Ni, Zn, and Hg concentrations were between 1 to 141 mg·kg^{-1} in non-amended soil and 1 to 615 mg·kg^{-1} in SDS-treated soil. The Ni concentration of non-amended soil was two times greater than the allowable limits. The parent material of Bursa soils is rich in Ni, and large chromite deposits with high Ni contents are located at high altitudes near Bursa. As a result, several state-owned and private sector mining companies are operated to extract Ni and Cr. Thus, the soils are naturally high in Ni. The concentration of heavy metals in the SDS was lower than the recommended values for sewage sludge according to the USEPA 40

Table 6. Turf color and quality ratings (1 to 9), and clipping yields (g·m^{-2}) of a turf mixture at different application times, nitrogen sources, and nitrogen rates across 2 years (2007–2008 and 2008–2009 growing periods).

Application time	Nitrogen sources							
	AN[z]				Sun-dried sludge			
	Nitrogen rates (g·m^{-2})							
	0.0	2.5	5.0	7.5	0.0	2.5	5.0	7.5
	Color							
Monthly	4.0 d[y]	6.5 c	7.5 b	8.0 a	4.0 d	6.4 c	7.3 b	8.1 a
Spring + fall	4.0 d	6.8 d	7.6 bc	7.7 ab	4.0 d	6.7 d	7.4 c	7.9 a
Spring	3.9 e	5.3 d	5.8 c	6.3 b	3.7 f	5.6 c	6.3 b	6.7 a
Fall	3.9 e	6.5 d	7.2 bc	7.4 a	3.8 e	6.6 d	7.1 c	7.3 ab
	Quality							
Monthly	3.6 f	6.4 d	7.4 bc	7.7 a	3.6 f	6.2 e	7.2 c	7.5 ab
Spring + fall	3.7 e	7.0 c	7.3 b	7.6 a	3.8 e	6.5 d	7.2 b	7.7 a
Spring	3.6 d	5.3 c	5.4 c	5.5 c	3.6 d	5.5 c	6.0 ab	7.2 a
Fall	3.8 d	6.3 c	7.0 b	7.1 ab	3.7 d	6.4 c	7.0 ab	7.2 a
	Clipping yields							
Monthly	3.6 f	107.4 d	193.4 c	244.4 b	3.2 f	82.0 e	195.6 c	294.8 a
Spring + fall	17.8 g	177.6 e	229.4 c	313.6 a	20.4 g	113.0 f	185.0 d	276.2 b
Spring	2.6 f	147.0 d	225.4 b	283.4 a	1.6 f	77.8 e	171.6 c	228.4 b
Fall	1.2 d	83.0 c	148.6 b	181.8 a	0.2 d	71.4 c	141.0 b	172.4 a

[z] AN = ammonium nitrate.

[y] Mean values within an application time followed by the same letter are not significantly different at 0.05 level using the least significant difference test.

Table 7. Color and quality ratings (1 to 9) and clipping yields (g·m^{-2}) of a turf mixture at different seasons, application times, and nitrogen sources across 2 years (2007–2008 and 2008–2009 growing periods).

Application time	Nitrogen sources							
	Spring		Summer		Fall		Winter	
	AN[z]	SDS	AN	SDS	AN	SDS	AN	SDS
	Color							
Monthly	7.0 cd[y]	6.6 d	6.7 ab	6.8 a	6.6 b	6.6 b	5.9 ab	5.8 ab
Spring + fall	7.3 ab	6.9 cd	5.8 d	6.3 c	7.2 a	7.1 a	5.9 ab	5.7 b
Spring	7.6 a	7.1 bc	6.3 c	6.4 bc	4.3 d	5.5 c	3.2 c	3.4 c
Fall	5.8 e	5.8 e	5.6 d	5.5 d	7.4 a	7.3a	6.2 a	6.2 a
	Quality							
Monthly	6.7 bc	6.3 c	6.3 a	6.5 a	6.4 b	6.1 b	5.7 ab	5.6 b
Spring + fall	7.0 ab	6.5 c	6.2 a	6.4 a	6.8 a	6.9 a	5.7 ab	5.5 b
Spring	7.4 a	6.7 bc	5.7 b	6.2 a	3.7 d	5.2 c	3.0 c	3.3 c
Fall	5.7 d	5.6 d	5.7 b	5.6 b	6.9 a	7.0 a	5.8 ab	6.1 a
	Clipping yield							
Monthly	217.4 c	200.2 cd	165.0 bc	211.2 a	166.4 b	164.0 b	—	—
Spring + Fall	408.0 a	290.8 b	120.0 de	85.6 ef	200.4 ab	218.0 a	—	—
Spring	420.6 a	272.6 b	195.2 ab	146.8 cd	42.2 c	59.8 c	—	—
Fall	165.6 de	145.2 e	64.8 fg	37.0 g	186.2 ab	192.6 ab	—	—

[z] AN = ammonium nitrate; SDS = sun-dried sludge.

[y] Mean values within a season followed by the same letter are not significantly different at 0.05 level using the least significant difference test.

Table 8. Turf color and quality ratings (1 to 9) and clipping yields ($g\cdot m^{-2}$) of a turf mixture at different seasons, application times, and nitrogen rates across 2 years (2007–2008 and 2008–2009 growing periods).

	Nitrogen rates ($g\cdot m^{-2}$)															
	Spring				Summer				Fall				Winter			
Application time	0.0	2.5	5.0	7.5	0.0	2.5	5.0	7.5	0.0	2.5	5.0	7.5	0.0	2.5	5.0	7.5
	Color															
Monthly	4.3 h[z]	6.8 f	7.7 de	8.4 bc	4.7 h	6.5 c–e	7.5 b	8.2 a	4.1 h	6.5 e	7.6 d	8.2 bc	3.0 fg	6.0 de	6.9 c	7.5 a
Spring + fall	4.6 h	7.4 e	8.1 cd	8.5 a–c	4.8 h	6.0 fg	6.4 d–f	6.8 cd	3.7 h	7.8 cd	8.5 ab	8.6 ab	3.0 fg	5.8 e	7.0 bc	7.4 ab
Spring	4.2 h	7.7 de	8.7 ab	8.9 a	4.3 h	6.2 ef	6.9 c	7.9 ab	3.7 h	4.8 g	5.2 g	5.8 f	3.0 fg	3.2 fg	3.3 fg	3.5 f
Fall	4.2 h	5.9 g	6.6 f	6.7 f	4.5 h	5.5 g	6.0 fg	6.2 ef	3.7 h	8.3 b	8.6 ab	8.8 a	3.0 fg	6.4 d	7.4 ab	7.9 a
	Quality															
Monthly	4.0 g	6.6 e	7.6 d	7.9 b–d	3.9 f	6.4 d	7.4 ab	7.9 a	3.7 h	6.4 e	7.4 d	7.5 cd	3.0 f	5.9 de	6.7 a–c	7.1 ab
Spring + fall	4.4 g	6.9 e	7.7 cd	8.1 a–c	4.1 f	6.7 cd	6.9 bc	7.4 ab	3.7 h	7.6 b–d	7.9 a–d	8.2 a	3.0 f	5.7 e	6.6 bc	7.1 ab
Spring	3.9 g	7.6 d	8.3 ab	8.6 a	4.1 f	6.3 d	6.6 cd	6.8 cd	3.5 h	4.6 g	4.7 fg	5.1 f	3.0 f	3.1 f	3.1 f	3.4 f
Fall	4.2 g	5.7 f	6.4 e	6.5 e	4.2 f	5.7 e	6.4 cd	6.5 cd	3.6 h	7.8 a–d	8.1 a–c	8.2 ab	3.0 f	6.3 cd	7.0 ab	7.3 a
	Clipping yields															
Monthly	12.2 ij	164.4 g	273.4 ef	385.2 cd	1.4 e	99.8 cd	268.4 b	383.0 a	0.0 h	114.8 f	236.2 c–e	310.0 ab	—	—	—	—
Spring + fall	65.6 hi	288.4 ef	223.4 bc	610.4 a	10.8 e	56.8 de	119.6 c	224.4 b	0.0 h	216.4 de	285.8 a–c	334.8 a	—	—	—	—
Spring	7.2 ij	326.0 de	484.0 b	569.4 a	1.2 e	97.2 cd	243.6 b	342.6 a	0.0 h	26.4 gh	66.2 fg	111.8 f	—	—	—	—
Fall	0.0 j	101.6 h	255.4 f	284.8 ef	0.0 e	15.8 e	52.0 e	136.0 c	2.6 h	195.4 e	271.6 b–d	287.6 a–c	—	—	—	—

[z] Mean values within a season followed by the same letter are not significantly different at 0.05 level using the least significant difference test.

Table 9. Maximum allowable heavy metal concentrations ($mg\cdot kg^{-1}$) in soil and sludge according to USEPA (2010) and European Union (1986) and metal concentrations ($mg\cdot kg^{-1}$) in the sun-dried sludge (SDS) and SDS-amended soils.

	USEPA 40CFR Part 503[z]	EU Council Directive 86/278/EEC[y]			SDS-amended soils			
Parameters	Sludge	Soil	Sludge	SDS	Control	30 $g\cdot m^{-2}$ N	60 $g\cdot m^{-2}$ N	90 $g\cdot m^{-2}$ N
Pb	840	50–300	750–1200	<20	22.4	22.1	22.7	22.8
Cd	85	1–3	20–40	<1	<1	<1	<1	<1
Cu	4300	50–140	1000–1750	100	46.4	46.1	46.8	47.8
Ni	420	30–75	300–400	80.4	141	156	148	137
Zn	7500	150–300	2500–4000	615	85.3	73.9	83.7	92.7
Hg	57	1–1.5	16–25	<2	<2	<2	<2	<2

[z] USEPA (2010).

[y] European Union (1986).

N = nitrogen; Pb = lead; Cd = cadmium; Cu = copper; Ni = nickel; Zn = zinc; Hg = mercury.

CFR Part 503 regulations and EU Council Directive 86/278/EEC (European Union, 1986; USEPA, 2010). Therefore, compared with the background values of base soils, SDS did not increase the level of heavy metals in the amended soil, even when the highest rates were applied.

In the present study, the application of SDS at rates necessary to provide sufficient N for turfgrass growth did not pose potential health risks with respect to heavy metals. This result is in agreement with those of Cheng et al. (2007), who reported that composted sewage sludge improved the soil nutrient supply for turfgrass growth without accumulating heavy metal and soluble salts in the soil. However, our results are not in accordance with those obtained by other researchers (Dai et al., 2007; Gardiner et al., 1995; Singh and Agrawal, 2007; Udom et al., 2004), who reported that heavy or toxic metals in sewage sludge resulted in the accumulation of heavy metals, which threatens long-term soil quality. The low concentration of heavy metals in the SDS used in the present study was likely because the material was collected from the activated sludge system of a food processing and canning company, not an industrial manufacturing source.

Several studies indicate that repeated, long-term application of sewage sludge to agricultural lands increases the total and available P content of the soil and enhances P losses to streams. Therefore, excess P in soils amended with organic sources could impair water quality, especially fresh water. The mobilization of P in surface runoff after sludge application is likely to contribute to the eutrophication of surface water (Bossche et al., 2000; Siddique and Robinson 2004; Withers et al., 2001). In the present study, the original soils contained 703 $mg\cdot kg^{-1}$ of total P, and the total P concentration in the soil after SDS was applied for 2 years at a rate of 30, 60, and 90 g of N/m^2 year was 600, 699, and 723 $mg\cdot kg^{-1}$, respectively. Phosphorus contents of the original and SDS-amended soils were similar at the end of 2-year experimental period.

Municipal liquid wastes may contain 4000 to 15,000 $mg\cdot kg^{-1}$ of P (Tchobanoglous and Burton, 1991), and P levels can reach 56,000 $mg\cdot kg^{-1}$ in municipal wastewater (Sotirakou et al., 1999). As a result of the relatively low concentration of P in the SDS (7318 $mg\cdot kg^{-1}$), SDS application did not increase the total P content of the soil. However, the build-up of soil P may occur after repeated, long-term applications of the SDS, particularly when high dosages are applied. Therefore, the P content of the soil must be constantly monitored in long-term trials to minimize the risk of environmental pollution.

The EC of the SDS (1910 µmhos/cm) was high, indicating that the material was relatively salty; thus, the soil salinity after SDS application was determined. The EC of the original soil was equal to 134 µmhos/cm. At the end of the experiment, the EC of soil receiving 30, 60, and 90 $g\cdot m^{-2}$ of N were 159, 175, and 183 µmhos/cm, respectively, indicating that salts did not accumulate after SDS application.

In the present study, fecal coliform regrowth was not detected in periodically sampled (monthly), sludge-amended soil samples. Moreover, if fecal coliform bacteria were present in the SDS, they did not survive or compete well in the soil environment. Several factors such as competition with native soil microorganisms, variations in ambient temperature, moisture, and solar radiation may reduce the survival time of microorganisms obtained from sludge (Kocaer et al., 2004).

Conclusions

The results of the present study suggested that SDS obtained from a food processing company's wastewater system can be used an N fertilizer for turfgrass without increasing the risk of contaminating the soil with heavy metals or other chemicals. Turf growth and quality responses were equivalent to those obtained from synthetic, soluble N fertilizers.

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