Changes in chemical properties of soil and sour cherry as a result of sewage sludge application

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Abstract

Angin I., Aslantas R., Kose M., Karakurt H., Ozkan G., 2012. **Changes in chemical properties of soil and sour cherry as a result of sewage sludge application**. Hort. Sci. (Prague), *39*: 61–66.

This study, aimed at assessment of the effects of different sewage sludge application rates on heavy metal accumulation in the soil and in sour cherry leaves was carried out in the years 2005–2007. The rates applied were 0.0, 2.5, 5.0, 7.5, 10.0 and 12.5 kg of dry matter per tree. Eighteen uniform one-year-old Kütahya sour cherry trees on *Prunus mahaleb* rootstock were used. Sewage sludge not only improved soil chemical properties but also resulted in an increase of nutrient content in cherry leaves. Sewage sludge application increased heavy metal content of soils. However, this increase did not exceed the critical values and was not reflected in the leaf contents of heavy metals. The most effective application rate was 7.5 kg per tree. Studies should be continued to evaluate the effects of sewage sludge on vegetative and generative growth, yield and fruit quality parameters.

Keywords: biosolid; *Prunus cerasus*; soil chemical characteristics; leaf nutrient content; heavy metals

The use of wastes in agriculture, forestry and land reclamation has been increasingly identified as an important issue for soil fertility, soil conservation and residue disposal. Using wastes in agriculture helps not only to dispose these materials economically, but also reduces negative effects on the environment. Sewage sludge is a concentrated suspension of solids, largely composed of organic matter, usually rich in mineral nutrients. In addition to major plant nutrients, sewage sludge also contains trace elements that are essential for plant growth (Ergene 1985; Anonymous 1996). However, sewage sludge contains also heavy metals and soluble salts, which could be toxic to the soil (McGrath et al. 2000; Vaca-Paulín et al. 2006) and plants, and could be a source of contamination due to its potential leaching to groundwater (Gascó et al. 2005; Correa et al. 2006). Plant uptake is one of the major pathways by which land-applied sewage sludge contaminants enter the food chain (Chaney 1980).

To ensure the application of sewage sludge onto agricultural lands in a beneficial and environmentally acceptable manner, several countries have regulated the use of sewage sludge in agriculture. These regulations are mainly based on monitoring of heavy metal content of soil, regarding soil type and of heavy metal uptake by plants. Therefore, studies should be conducted to estimate the possible effects of sewage sludge application on heavy metal content of different soils and their uptake by plants.

Many studies were carried out to determine the effects of sewage sludge application on crop and plant yield and soil properties (Navas et al. 1998; Aggelides, Londra 2000; Holz et al. 2000; Tsadilas et al. 2005; Cheng et al. 2007). Aslantas et al. (2010) recently reported about vegetative organs and fruits of sour cherry as affected by sewage sludge application; however, no attention was given to the potential heavy metal contamination of soil and plants in their study. Therefore, the present study was focused at the assessment of effects of different sewage sludge application rates on heavy metal accumulation in the soil and in sour cherry leaves.

MATERIAL AND METHODS

This study was conducted in the years 2005–2007 at the Department of Horticulture of the Atatürk University, in the Research and Experimental Orchard, in Erzurum, Turkey, located at 39°55'N, 41°61'E. The region is situated in a zone of semiarid climate. The long-term mean annual minimum temperature is –8.7°C and mean maximum temperature 19.5°C, mean relative humidity 64% and mean annual rainfall 447 mm. Soils of the experimental site are alluvial, of hydromorphic origin. The territory of the experiment has only a slight slope (< 2%), so no runoff was noticed during the study.

The experiment was set up in a completely randomized block design with six sewage sludge application rates and with three replications. One-year-old, virus-free Kütahya sour cherry trees on *Prunus mahaleb* rootstock were used for the experiment. They were planted at 4 × 5 m in April 2005. A single tree served as replication. To get a more uniform tree growth, shoots were decapitated at 75 cm above the graft union. Weeds were controlled around the trees by repeated hoeing. No pesticide was applied. Anaerobically stabilized sewage sludge, obtained from the Ankara Municipality Treatment Plant, was applied in May 2005, at the rates of 0.0 (control), 2.5, 5.0, 7.5, 10.0 and 12.5 kg of dry matter per tree. No sewage sludge application was employed after that date. Sewage sludge was applied to the apparent root extension area (70 cm in diameter), to the depth of 20 cm, trying to avoid considerable root damage.

Initial soil properties and characteristics of sewage sludge are presented in Table 1. Initial and final soil samples were taken in April 2005 and July 2007, respectively. The pH and electrical conductivity

Table 1. Initial characteristics of soil and of sewage sludge used in the study

Parameter and unit (in relation to dry matter)		Soil	Sewage sludge
Texture	clay (%)	11.40	–
	silt (%)	19.40	
	sand (%)	69.20	
Organic matter (%)		0.55	34
Total N (%)		NH_4 0.001 NO_3 0.001	4.46
Total P (%)		1.22	1.10
Cation exchange capacity (m.e./100 g)		22.87	62.43
Ca (m.e./100 g)		17.18	37
Mg (m.e./100 g)			15.83
Na (m.e./100 g)		0.07	0.87
K (m.e./100 g)		0.86	5.38
Fe (ppm)		0.85	1,000
Zn (ppm)		0.43	873.53
Cu (ppm)		0.24	239.90
Mn (ppm)		1.52	903.99
Ni (ppm)		0.25	57
Pb (ppm)		0.25	152.5
Cd (ppm)		–	8.5
pH		7.34	6.82
Electrical conductivity (mS/cm)		0.29	6.54
Lime (%)		0.17	17.3
Salmonella (25 g)		–	not found
Helmint egg (g)		–	not found

(EC) was measured in 1:2.5 (soil:water) extracts according to Demiralay (1993) and Rhoades (1996). Soil organic matter was determined by using the Smith-Weldon method as described by Nelson and Sommers (1982). Lime content of the soils was determined with the "Scheibler Calcimeter" as described by Nelson (1982). $C_2H_7NO_2$ buffered at pH 7 (Rhoades 1982) was used to determine exchangeable cations. Cation exchange capacity (CEC) was determined with a flame photometer (Jenway PFP-7, Essex, UK) using $C_2H_3NaO_2$-$C_2H_7NO_2$ buffer at pH 7 according to Sumner and Miller (1996). Phosphorus was determined colorimetrically with the molybdate-ascorbic acid procedure as described in Murphy and Riley (1962). Mineral nitrogen was determined using the fractionated steam distillation with MgO

Table 2. Effects of sewage sludge application on soil chemical properties

SS*	pH	EC (mS/cm)	Lime (%)	OM (%)	P (ppm)	CEC	Na	K	Ca + Mg
						m.e./100 g soil			
0.0	7.47^{b}	0.13	0.23^{d}	0.42^{c}	1.31^{c}	23.2^{c}	0.139	0.605^{c}	12.10^{c}
2.5	7.50^{a}	0.13	0.51^{c}	0.58^{b}	4.99^{b}	25.4^{b}	0.138	0.646^{b}	12.93^{b}
5.0	7.49^{ab}	0.15	0.70^{bc}	0.61^{b}	6.59^{a}	25.5^{b}	0.138	0.642^{bc}	12.84^{b}
7.5	7.43^{c}	0.14	0.82^{ab}	0.59^{b}	6.90^{a}	25.9^{ab}	0.151	0.614^{bc}	12.28^{b}
10.0	7.37^{d}	0.15	0.99^{a}	0.73^{a}	7.69^{a}	26.9^{a}	0.149	0.697^{a}	13.94^{a}
12.5	7.41^{c}	0.10	0.69^{bc}	0.61^{b}	7.63^{a}	27.1^{a}	0.145	0.693^{a}	13.85^{a}
α	< 0.05	ns	< 0.05	< 0.05	< 0.05	< 0.05	ns	< 0.05	< 0.05

SS*	NH_4	NO_3	Fe	Mn	Zn	Cu	Ni	Pb	Cd
	(ppm)								
0.0	13^{bc}	12^{b}	0.89^{d}	2.30^{d}	0.30^{f}	0.26^{e}	0.25^{d}	0.24^{e}	0.03^{c}
2.5	6^{c}	22^{a}	1.95^{c}	2.03^{e}	5.97^{e}	0.72^{d}	0.31^{c}	1.98^{d}	0.05^{bc}
5.0	19^{b}	11^{b}	2.29^{c}	2.53^{cd}	7.22^{d}	0.83^{c}	0.32^{c}	2.40^{c}	0.05^{bc}
7.5	19^{b}	12^{b}	2.97^{b}	2.58^{c}	9.57^{c}	1.13^{b}	0.36^{b}	2.76^{bc}	0.08^{ab}
10.0	27^{a}	22^{a}	3.95^{a}	2.89^{b}	14.94^{a}	1.49^{a}	0.39^{a}	3.57^{a}	0.11^{a}
12.5	29^{a}	21^{a}	3.22^{b}	3.23^{a}	12.26^{b}	1.20^{b}	0.40^{a}	2.84^{b}	0.08^{ab}
α	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

*application rates of sewage sludge (0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 kg of dry matter/tree); OM – organic matter; CEC – cation exchange capacity; EC – electrical conductivity; ns – non-significant; values followed by the same letter are not significantly (at α = 0.05) different

for ammonium (NH_4-N) and Dewarda's alloy for nitrate (NO_3-N) (Bremner 1965). Microelement contents were determined in the DTPA extracts, according to Lindsay and Norwell (1978), using a Perkin-Elmer Optima 2100 DV optical emission spectrometer (ICP) (Perkin-Elmer, Waltham, USA).

Leaf samples, taken on July 20, 2007 were dried for 48 h at 65 ± 5°C and ground to pass 1 mm. The mineral nutrient and heavy metal contents of leaves were determined using HNO_3-$HClO_4$ acid mixture digestion (AOAC 1990). K, Ca, Mg, Na, Fe, Cu, Zn, Mn, Ni, Pb, and Cd were determined in the extracts obtained, by Perkin-Elmer Optima 2100 DV optical emission spectrometer (ICP). Phosphorus was determined spectrophotometrically by the indophenol-blue method at 660 nm with AquaMate UV/VIS spectrophotometer (Thermo Spectronic, Cambridge, UK). The Kjeldahl method and a Vapodest 10 Rapid Distillation Unit (Gerhardt, Königswinter, Germany) were used to determine N contents.

Analysis of variance was performed by the SPSS Statistical Package (SPSS 2004) using GLM. The Duncan's multiple range test was used for mean separation, at the level of significance α = 0.05.

RESULTS AND DISCUSSION

Effect of sewage sludge on soil pH was found to be significant. Sewage sludge applied at the rates above 7.5 kg per tree significantly decreased soil pH (Table 2). This decrease could be related to pH value (6.82) of the sewage sludge (Table 1) and organic acids produced in the mineralization process (Veeresh et al. 2003; Asik, Katkat 2004). However, sewage sludge application did not cause any changes in soil electrical conductivity, apparently due to textural class (SL) of the soil, which could favour leaching, as mentioned by Perez-Murcia et al. (2006) and by Gascó and Lobo (2007). Sewage sludge, due to its high lime content (17.3%), significantly increased lime content of soil at all application rates. Similar increases were observed for organic matter content (Table 2). The same results were reported by Albiach et al. (2001), Hernández-Apaolaza et al. (2005), Tsadilas et al. (2005) and Cheng et al. (2007). Organic matter, ammonium (NH_4-N) and nitrate (NO_3-N) contents of soil increased with increasing sewage sludge application rates (Table 2). Increase in am-

Table 3. Amount of metals incorporated into the soil by sewage sludge application (kg/ha)

Sludge application rate (kg/tree)[a]	Zn	Cu	Ni	Pb	Cd
2.5	1.09	0.30	0.07	0.19	0.01
5.0	2.19	0.60	0.14	0.38	0.02
7.5	3.28	0.90	0.21	0.57	0.03
10.0	4.38	1.20	0.29	0.76	0.04
12.5	5.47	1.50	0.36	0.95	0.05
Critical soil concentration[b]	480	150	120	480	9.6
European regulations[b]	300	120	30	150	1.5
USEPA[b]	2,800	1,500	420	300	39

[a]application rates were calculated considering 500 trees/ha (4 × 5 m spacing); [b]according to Gascó and Lobo (2007)

monium and nitrate content of soils could be due to the amount of N contained in the applied sewage sludge (Hernández-Apaolaza et al. 2005; Mantovi et al. 2005; Weber et al. 2007).

Cation exchange capacity (CEC) of soils increased with increasing sewage sludge application rates and was the highest at the rates of 10.0 and 12.5 kg per tree (Table 2). This tendency could be related to the high CEC value of sewage sludge itself (62.43 m.e./100 g) and to an increase of the adsorption surface. Macro- and microelement contents of soils were increased with the increasing sewage sludge application rates (Table 2). K, Ca, and Mg, which are considered as limiting factors of agricultural productivity, when present at low levels, increased with sewage sludge application. However, rates above 7.5 kg per tree showed fluctuations in nutrient and metallic element contents in the soil, probably due to the textural class (SL) of soil, which could favour leaching.

Sewage sludge application increased the contents of metallic elements in the soil. However, increase in the content of these elements in the soil did not exceed the critical values reported by Gascó and Lobo (2007) as the European and USEPA regulations. Amount of metals incorporated into the soil with the sewage sludge were much lower than critical values (Table 3).

In addition to soil chemical properties, sewage sludge application also caused significant changes in chemical properties of sour cherry leaves (Table 4). Sewage sludge application significantly increased N, P, and K contents of leaves at all application rates, apparently due to their increase in the soil. The highest values were reached with the application of 7.5 kg per tree. Considering the standard values recommended for sour cherry leaves N, P, and K content reached to sufficient levels only with the application of 7.5 kg per tree (Hanson, Proebsting 1996). While Ca was sufficient, Mg was inadequate at all applications. Ca and Mg content of leaves showed fluctuations among the applications. Na, Cu, Zn, Mn, Ni, and Pb content of leaves increased with the increasing levels of these elements in the soil. Iron content decreased with the increasing sewage sludge rates, apparently due to the increase of P and Ca content of the soil; this was in line with the report of Kabata-Pendias and Pendias (2001). Although Cd was determined in the soil, it was not detected in plant leaves. The obtained results showed that heavy metal contents of sour cherry leaves were much lower than critical values. No abnormalities were noted in the trees under study throughout the 3-year study.

Table 4. Effects of sewage sludge application on mineral element concentration in cherry leaves (ppm d.m.); 3-year mean values

SS*	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	Ni	Pb	Cd
0.0	1.9^{b}	$1,004^{b}$	$10,425^{ab}$	$9,590^{a}$	$4,071^{a}$	10^{d}	114^{a}	3.0	3.1^{c}	17.4^{b}	1.8^{abc}	0.2^{c}	not detected
2.5	2.0^{b}	$1,170^{ab}$	$9,324^{bc}$	$9,041^{ab}$	$3,660^{a}$	17^{c}	103^{ab}	4.2	5.0^{a}	18.1^{b}	2.0^{a}	0.7^{b}	
5.0	1.9^{b}	$1,326^{ab}$	$8,266^{c}$	$9,996^{a}$	$3,980^{a}$	19^{bc}	102^{ab}	3.5	3.9^{bc}	16.9^{b}	2.0^{a}	1.0^{a}	
7.5	2.4^{a}	$1,558^{a}$	$11,533^{a}$	$7,657^{b}$	$2,727^{b}$	24^{ab}	96^{ab}	3.8	4.4^{ab}	16.2^{b}	1.6^{bc}	1.1^{a}	
10.0	2.0^{b}	$1,363^{ab}$	$9,119^{bc}$	$5,900^{c}$	$2,536^{b}$	24^{ab}	80^{b}	4.0	3.7^{bc}	16.0^{b}	1.4^{c}	1.2^{a}	
12.5	1.9^{b}	$1,430^{ab}$	$9,708^{bc}$	$9,354^{a}$	$3,970^{a}$	29^{a}	100^{ab}	3.9	3.9^{bc}	22.4^{a}	1.9^{ab}	1.1^{a}	
α	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	ns	< 0.05	< 0.05	< 0.05	< 0.05	–

*application rates of sewage sludge (0.0, 2.5, 5.0, 7.5, 10.0 or 12.5 kg of dry matter/tree); ns – non-significant; values followed by the same letter are not significantly (α = 0.05) different

CONCLUSIONS

Results obtained in this study have shown that sewage sludge is an effective means for improvement of soil and plant chemical properties in light textured soils. The most effective application rate was 7.5 kg per tree. Application of sewage sludge may improve soil properties. However, its effect apparently depends on ecological conditions and plant species. In order to minimize negative effects of sewage sludge to a soil, characteristics of a given sewage sludge should be taken into account, the critical concentrations of heavy metals in particular. Using sewage sludge as a soil reclamation material in agriculture may help not only to dispose these materials economically, but also to reduce its eventual negative effects on environment. Further studies should be conducted to evaluate the effects of sewage sludge on vegetative and generative growth, yield, and fruit quality parameters on plants. It must be also assessed – for how many years the heavy metal accumulation will be below the critical values.

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Received for publication January 7, 2011
Accepted after corrections November 10, 2011

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