Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 21(2009) 1438–1445
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Long-term impact of municipal sewage irrigation on treated soil and black locust trees in a semi-arid suburban area of Iran

Masoud Tabari, Azadeh Salehi*

Department of Forestry, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Tehran 14115-111, Iran. E-mail: salehi.azadeh@yahoo.com

Received 04 November 2008; revised 15 March 2009; accepted 08 April 2009

Abstract

The effects of municipal sewage irrigation on the soil and black locust (*Robinia pseudoacacia* L.) tree were studied. For this purpose, two artificial black locust stands under irrigation of municipal sewage and well water were selected in south of Tehran, Iran. Data were collected using technique of systematic random sampling with 4 replicates in each stand. It was found that the growth of black locust tree, as indicated by diameter at breast height, total height, crown length, average crown diameter, basal area and volume, in sewage irrigation stand was much higher than that of well water irrigation stand ($P < 0.01$). Plant analysis indicated that concentrations of leaf nutrients (N, P, K, Ca, Mg, Na, Fe, Mn, Cu and Zn) were greater in sewage-irrigated trees, without toxicity to the minerals of tree leaf, than those of well waterirrigated trees, and positively correlated with their respective value in soil. Ni, Cr and Pb were not detected in leaf samples. Application of sewage resulted in a 1.5-fold increase in the concentrations of soil nutrients, Ni, Cr and Pb. Among these minerals only Pb and Ni in some soil samples exceeded the toxicity limit. The increase in pH, electrical conductivity (EC) and organic carbon of soil was also observed in sewage irrigation. Results confirm that besides the use as irrigation water, municipal sewages are also a potential source of plant nutrients. However, significant accumulation of heavy metals such as Pb and Ni in soil needs to be monitored.

Key words: afforestation; irrigation; municipal sewage; black locust; nutrient; heavy metal

DOI: 10.1016/S1001-0742(08)62437-7

Introduction

The economic development of the society towards large-scale urbanization and industrialization is leading to the production of huge quantities of sewage (Singh and Agrawal, 2008). Industrial and municipal sewages are used on land for irrigation purposes that create both opportunities and problems (Gerhart *et al*., 2006).

Establishment of tree plantations following sewage irrigation has been a common practice for many years. Several examples of sewage irrigated plantations in some regions of India (Singh and Bhati, 2005), Australia (Stewart and Flinn, 1984; Sharma and Ashwath, 2006), and New Zealand (Guo *et al*., 2002) are available. The practice not only reduces the toxicity of soil and plays an important role in safeguarding the environment (Stewart and Flinn, 1984), because woody species may utilize sewage and uptake heavy metals through extensive root systems and retain them for a long time (Madejoón *et al*., 2006), but it also creates opportunities for commercial biomass production and sequestration of excess minerals in the plant system (Sharma and Ashwath, 2006). Accordingly, the use of sewage in afforestations is a viable option for the economic disposal of sewage (Bhati and Singh, 2003). Moreover, municipal sewage is rich in organic matter and also contains appreciable amounts of nutrients (Gupta *et al*., 1998). Hence, nutrient levels of soil are expected to improve considerably using continuous irrigation with municipal sewage (Ramirez-Fuentes *et al*., 2002).

Sewage may contain amounts of potentially harmful components such as heavy metals and pathogens (Rattan, *et al*., 2005; Toze, 2006). The effects of microbial pathogens are usually short term and vary in severity depending on the potential for human, animal or environmental contact (Toze, 2006), while the heavy metals have longer term impacts that could be a source of contamination and be toxic to the soil (Sharma *et al*., 2007) and plant (Gascó and Lobo, 2007). Hence, if sewage is to be recycled safely for irrigation, the problems associated with using it need to be known (Emongor and Ramolemana, 2004). Because of differences in climatic, vegetation, social and cultural conditions and also changes in qualities of soil and sewage among different regions and even within different time periods in one region, utilizing only the applicable guidelines to other regions of the world would be a mistake and in long-term would damage the soil and water resources, therefore, the specific local research works need to be carried out.

* Corresponding author. E-mail: mtabari@modares.ac.ir

Black locust (*Robinia pseudoacacia* L.) is native to the southeastern United States, but it has been widely planted and naturalized elsewhere. Black locust belongs to nitrogen-fixing plants, for this reason it can grow on poor soils and improve soil fertility. In Iran it is often planted alongside streets, in green space and parks, especially in large cities, because it tolerates pollution well (Mossadegh, 1993). The utilization of municipal sewage for black locust irrigation in suburban areas could be beneficial for the economic disposal of sewage and the production of wood.

There are very few studies from Iran related to effects of municipal sewage irrigation on trees and surrounding soil. The objectives of this investigation were to quantify the growth of black locust trees under municipal sewage irrigation and to assess the effects of long-term irrigation with sewage on nutrient and heavy metal contents of tree leaf and soil.

1 Materials and methods

1.1 Description of study area

The study area is located in Shahr-e-Rey, 5 km south of Tehran-Iran (Latitude 35°37′N, Longitude 51°23′E, 1005 m above sea level). The climate of the area is semi-arid with mild-cold winters and seven months (mid April–mid November) dry season. Average annual rainfall and average annual temperature are 232 mm and 13.3°C, respectively. The highest rainfall is in March (41.32 mm) and the lowest in August (0.89 mm). The warmest month is August and the coldest is January.

Experiments were conducted at two even-aged (15 years) artificial stand of black locust in October 2006. The first stand was irrigated with municipal sewage and the second by well water since they were planted. Durations of irrigation were based on tree water-use and the potential evapo-transpiration, which varied seasonally in response to the climate, and on an average the irrigations were carried on 8-d periods for 8 months/year (April–November). The soils of two stands were both clay-loam (according to US soil taxonomy) with 29.25% clay, 36.20% silt and 34.55% sand in the stand irrigated with municipal sewage and 27.14% clay, 37.86% silt and 35% sand with well water.

1.2 Measurements and sampling

Data were collected using technique of systematic random sampling (Jayaraman, 2000) with 4 replications in each stand. Four plots were identified in each stand. Plots were 30 m × 30 m, with tree spacing of 3 m × 4 m. In each plot, diameter at breast height (d.b.h.), total height, crown length and crown diameter of trees were measured and basal area computed. Standing volume of each tree was determined by using form factor (ca. 0.5) and formula made by Zobeiri (1994).

$$V = 0.4 \times D^2 \times H$$

where, D (cm) is the diameter at breast height (d.b.h.), H (m) is the total height, and V (m^3) is the standing volume.

In each plot, four trees were selected and in the growing season leaf samples of black locust trees taken from the top of crown and the part affected by sunlight (Letacon, 1969; Habibi, 1992). This collection provided 16 leaf samples in each treatment. At the end of the sampling, one representative leaf sample from each plot (by mixing of four samples of each plot) was taken for chemical analysis. Soil samples were taken under each selected tree from the root zone at a depth interval of 0.15 m down to 0.6 m by digging profiles. This collection provided 48 soil samples in each treatment from three depths (0–0.15, 0.15–0.3 and 0.3–0.6 m). At the end of soil sampling, three representative soil samples of three depths from each plot were taken by mixing of samples of each layer in each plot for chemical analysis according to Habibi (1992). Municipal sewage and well water were sampled daily (3 d per month) from early June to late November at three-hour intervals (7:00 am, 13:00 pm and 19:00 pm) to make a composite sample of each day.

1.3 Laboratory analysis

Water samples were brought to the laboratory in resistant plastic bottles to avoid adherence to the container wall. They were filtered through a Whatmann 42 mm filter paper and stored at 4°C to minimize microbial decomposition of solids (Yadav *et al*., 2002; Singh and Bhati, 2005). pH and electrical conductivity (EC) were measured by the procedure described in OMA (1990), NH_4^+-N, NO_3^--N, PO_4^{3-}-P, K, Ca, Mg and Na as the method given by APHA (1992). Cu, Fe, Mn, Zn, Ni, Cr and Pb were estimated by the aqua regia method of Jackson (1973) and their concentrations were measured using an Atomic Absorption Spectrophotometer (model-3110, Perkin-Elmer, Boesch, Huenenberg, Switzerland).

The soil samples were air-dried, crushed, passed through a 2-mm sieve and analyzed for various physico-chemical properties. Soil texture was determined using the hydrometer method according to Bouyoucos (1962). Soil pH and EC (1:2 (*w/w*) of soil-water ratio) were determined using standard procedures (Jackson, 1973). Soil organic carbon (SOC) content was determined by the Walkley-Black method (Nelson and Sommers, 1996). Calcium carbonate ($CaCO_3$) was measured with a calcimeter. Soil elements (K, Ca, Mg, Na, Cu, Fe, Mn, Zn, Ni, Cr and Pb) was extracted after digestion with 3:1 (*V/V*) concentrated HCl-HNO_3 and measured by Atomic Absorption Spectrophotometer (Gascó and Lobo, 2007). Extractable P was determined by the extraction method of Olsen *et al*., (1954). Total N was analyzed by the Kjeldahl method (Yadav *et al*., 2002).

Fresh weight of some leaves from each treatment was recorded immediately after harvest. The dry weight of them was recorded after oven drying for 72 h at 80°C. Leaf samples were washed using tap water, rinsed with distilled water, oven dried at 80°C for 24 h, ground in a stainless steel mill and retained for mineral analysis (Singh and Bhati, 2005). For the determination of leaf elements except N and P, the leaf samples were wet digested as described by Jackson (1973) followed by a measurement of concentrations using an Atomic Absorption Spectrophotometer. The measurement of N and P content was performed after a wet digestion, respectively using the Kjeldahl method, and using UV-Vis spectrophotometer (Systronix model 117, Ahmedabad, India) at 420 nm (Jackson, 1973).

1.4 Statistical analysis

Average growth parameters, leaf elements and soil physico-chemical properties of two irrigation treatments (T1: irrigation by municipal sewage; T2: irrigation by well water), were compared with independent-samples *t*-test (Pelosi and Sandifer, 2003). Simple linear regression analysis was used to determine the relationships between nutrient concentrations in soil liquid phase and tree leaf. Furthermore, the variations in characteristics of municipal sewage and well water were also tested using independent-samples *t*-test. All data were analyzed using the SPSS statistical package (Lindaman, 1992).

2 Results

2.1 Quality of municipal sewage and well water

The quality of municipal sewage and well water was assessed for irrigation with respect to their pH, EC, and concentration of nutrients and heavy metals (Table 1). Results indicated that the waters were alkaline in reaction. The pH of the municipal sewage in various months ranged from 7.51 to 7.75 and 6.69 to 7.62 for well water. The EC of municipal sewage ranged from 1.78 to 2.12 dS/m with the greatest value detected in August. The average EC of municipal sewage exceeded 1 dS/m (1.91 dS/m) indicating that this sewage was saline in nature (Rattan *et al*., 2005). The pH and EC of the municipal sewage were higher than the well water. The concentration of all the nutrients and heavy metals (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Ni, Cr and Pb) was higher in municipal sewage, with NO_3^--N (1.63 mg/L) content being 6.8 times the content in well water (0.24 mg/L). The content of NH_4^+-N in municipal sewage (9.05 mg/L) was also 4.2 times the content in well water (2.15 mg/L). The concentration of NH_4^+-N, Ca and Pb of municipal sewage and well water and Mg, Zn, Mn, Fe, Ni and Cr of municipal sewage was upon maximum permissible limits set for land use recommed by World Health Organization (WHO) (Table 1).

2.2 Irrigation impact on soil properties

Independent-samples *t*-test indicated that a fifteen-year application of municipal sewage resulted in an increase in pH, EC, organic carbon, $CaCO_3$, nutrients and heavy metals (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Ni, Cr and Pb) of sewage irrigated soil as compared to well water irrigated soil (Table 2). Increase in pH was 1.02 unit and EC 1.68 times in soil of sewage treatment compared to the soil of well water treatment. SOC as a basic index of soil playing a variety of roles in nutrient, water, and biological cycles was 1.17%–1.29% in municipal sewage irrigated soil, whereas it was 0.88%–1.14% in soil irrigated with well water. Soil of sewage and well water treatments both had the same soil texture (clay-loam). The concentrations of nutrients and heavy metals in the sewage irrigated soil were about 1.5 times higher than those of the well water irrigated soil. However, these elements, except Pb and Ni that exceeded the toxicity limit in some soil samples, did not exceed the threshold values limited by Salardini (1992), as evidenced by enhanced growth without any nutritive or morphological problems in the trees.

2.3 Tree growth

Irrigation with municipal sewage for 15 years produced the largest trees in this treatment. The most frequency of trees was found at diameter class of 18 and 12 cm, respectively grown on stands irrigated with municipal sewage and well water (Fig. 1). In fact, tree growth in sewage irrigation stand was much higher than that in well water irrigation stand ($P < 0.01$), as indicated by 16.62 ± 0.96 cm diameter at breast height, (9.31 ± 0.18) m height, (7.10 ± 0.08) m crown length, (2.40 ± 0.09) m crown average diameter, (225.90 ± 21.77) cm^2 basal area and (0.110 ± 0.011) m^3 standing volume (mean ± SE) of the trees in sewage irrigation stand (Fig. 2). Statistical analysis of correlations between diameter at breast height, height

Table 1 Characteristics of municipal sewage and well water

Parameter	Municipal sewage		Well water		WHO**
	Range	Mean ± SD	Range	Mean ± SD	
pH	7.51–7.75	7.63 ± 0.01 a*	6.69–7.62	7.32 ± 0.05 b	6.5–8.5
EC (dS/m)	1.78–2.12	1.91 ± 0.02 a	0.54–0.67	0.590 ± 0.008 b	3
NH_4^+-N (mg/L)	8.1–10.24	9.05 ± 0.11 a	1.83–2.49	2.15 ± 0.19 b	1.5
NO_3^--N (mg/L)	1.58–1.89	1.63 ± 0.09 a	0.19–0.33	0.24 ± 0.08 b	3
PO_4^{3-}-P (mg/L)	11.45–14.13	12.69 ± 0.16 a	4.62–5.64	5.03 ± 0.01 b	–
K (mg/L)	33.06–46.31	39.93 ± 0.83 a	17.48–22.75	19.72 ± 0.36 b	–
Ca (mg/L)	235.54–296.20	255.22 ± 4.57 a	66.70–101.57	96.77 ± 1.26 b	75
Mg (mg/L)	100.9–124.00	109.85 ± 1.83 a	28.9–42.00	35.22 ± 0.79 b	50
Na (mg/L)	135.90–150.22	140.45 ± 0.20 a	30.18–41.03	35.18 ± 0.13 b	200
Fe (mg/L)	5.44–7.25	6.33 ± 0.12 a	0.57–0.77	0.73 ± 0.01 b	3
Zn (mg/L)	2.91–4.20	3.30 ± 0.06 a	0.38–0.56	0.43 ± 0.07 b	3
Cu (mg/L)	1.06–1.97	1.26 ± 0.03 a	0.05–0.16	0.09 ± 0.01 b	1–2
Mn (mg/L)	3.57–6.71	5.01 ± 0.11 a	0.29–0.78	0.51 ± 0.09 b	1
Pb (mg/L)	0.08–0.15	0.106 ± 0.063 a	0.02–0.054	0.033 ± 0.026 b	0.01
Ni (mg/L)	0.05–0.12	0.081 ± 0.007 a	0.005–0.034	0.018 ± 0.002 b	0.02
Cr (mg/L)	0.07–0.14	0.104 ± 0.005 a	0.031–0.056	0.044 ± 0.002 b	0.05

* Different letters in row indicate significant ($P < 0.01$) difference; ** Hach, 2002.

Table 2 Physico-chemical properties of soils irrigated with municipal sewage and well water under the plantation of black locust trees

Parameter	0–0.15 m		0.15–0.3 m		0.3–0.6 m		Critical value**
	T_1	T_2	T_1	T_2	T_1	T_2	
pH	8.26 ± 0.08 a*	8.03 ± 0.07 b	8.17 ± 0.06 a	7.89 ± 0.02 b	8.08 ± 0.08 a	7.83 ± 0.08 b	6.0–9.0
EC (dS/m)	1.45 ± 0.04 a	0.850 ± 0.021 b	1.25 ± 0.08 a	0.777 ± 0.022 b	1.13 ± 0.12 a	0.660 ± 0.045 b	–
SOC (%)	1.43 ± 0.03 a	1.23 ± 0.16 b	1.26 ± 0.053 a	1.03 ± 0.126 b	1.01 ± 0.051 a	0.756 ± 0.080 b	–
$CaCO_3$ (%)	22.61 ± 0.60 a	20.56 ± 0.65 b	20.13 ± 0.92 a	18.30 ± 0.62 b	17.86 ± 0.33 a	16.76 ± 0.28 b	–
N (g/kg)	1.22 ± 0.17 a	0.792 ± 0.080 b	0.875 ± 0.009 a	0.662 ± 0.110 b	0.752 ± 0.051a	0.500 ± 0.145 b	0.2–5
P (mg/kg)	20.50 ± 1.29 a	17.75 ± 0.95 b	18.25 ± 0.95 a	14.50 ± 1.29 b	16.75 ± 1.70 a	13.75 ± 0.957 b	100–2000
K (g/kg)	3.75 ± 0.06 a	2.82 ± 0.14 b	3.43 ± 0.10 a	2.56 ± 0.17 b	3.20 ± 0.10 a	2.20 ± 0.10 b	1.7–33
Ca (g/kg)	27.43 ± 0.44 a	20.49 ± 0.77 b	26.29 ± 0.58 a	20.05 ± 1.11 b	24.65 ± 0.48 a	18.34 ± 0.59 b	0.7–36
Mg (g/kg)	0.405 ± 0.042 a	0.322 ± 0.020 b	0.378 ± 0.045 a	0.301 ± 0.019 b	0.334 ± 0.021 a	0.284 ± 0.010 b	1.2–15
Na (mg/kg)	1.22 ± 0.14 a	0.937 ± 0.035 b	1.09 ± 0.09 a	0.887 ± 0.027 b	0.055 a ± 0.947	0.843 ± 0.043 b	–
Fe (g/kg)	25.84 ± 1.64 a	20.12 ± 1.07 b	23.99 ± 1.47 a	19.69 ± 0.811 b	22.45 ± 0.964 a	17.54 ± 0.992 b	5–50
Zn (mg/kg)	175.95 ± 11.42 a	112.47 ± 4.32 b	148.77 ± 11.49 a	99.77 ± 2.51 b	141.85 ± 12.05 a	87.56 ± 7.17 b	10–500
Mn (mg/kg)	768.31 ± 17.59 a	652.18 ± 21.83 b	742.36 ± 9.81 a	641.91 ± 8.33 b	722.53 ± 9.32 a	617.12 ± 11.63 b	200–10000
Cu (mg/kg)	48.48 ± 1.63 a	29.38 ± 0.862 b	43.50 ± 1.10 a	27.43 ± 1.45 b	38.30 ± 1.70 a	26.48 ± 0.434 b	5–400
Pb (mg/kg)	98.65 ± 1.53 a	67.33 ± 3.43 b	93.01 ± 2.12 a	55.64 ± 2.14 b	74.81 ± 2.08 a	47.94 ± 2.89 b	40
Ni (mg/kg)	40 ± 0.36 a	29.41 ± 0.50 b	38.56 ± 0.22 a	27.63 ± 0.47 b	37.01 ± 0.44 a	24.28 ± 1.27 b	30
Cr (mg/kg)	58.92 ± 0.48 a	36.65 ± 0.40 b	48.04 ± 0.75 a	33.81 ± 0.61 b	42.67 ± 0.29 a	31.39 ± 0.46 b	500

T_1: municipal sewage irragation; T_2: well water irragation; EC: electrical conductivity; SOC: soil organic carbon.
* Values are mean of four replications ± SD; different letters in row indicate significant ($P < 0.01$) difference between T_1 and T_2.
** Salardini, 1992.

Table 3 Relationship between height, diameter and volume of trees with the concentration of soil NPK

Growth parameter	Linear regression
Height (m)	$H = 8.14S_N + 1.49$; $R^2 = 0.89$, $P < 0.01$
Diameter (cm)	$D = 14.9S_N + 2.31$; $R^2 = 0.90$, $P < 0.01$
Volume (m^3)	$V = 0.209S_N - 0.088$; $R^2 = 0.93$, $P < 0.01$
Height (m)	$H = 0.81S_P - 5.58$; $R^2 = 0.93$, $P < 0.01$
Diameter (cm)	$D = 1.44S_P - 9.89$; $R^2 = 0.87$, $P < 0.01$
Volume (m^3)	$V = 0.020S_P - 0.259$; $R^2 = 0.90$, $P < 0.01$
Height (m)	$H = 2.99S_K - 0.82$; $R^2 = 0.91$, $P < 0.01$
Diameter (cm)	$D = 5.27S_K - 1.24$; $R^2 = 0.87$, $P < 0.01$
Volume (m^3)	$V = 0.074S_K - 0.140$; $R^2 = 0.90$, $P < 0.01$

S_N, S_P, S_K mean the concentrations of N (g/kg), P (mg/kg), and K (g/kg) in soil.
Linear regression for all parameters is $P < 0.01$.

and volume of trees with quantity of soil NPK showed that these growth parameters were positively correlated with quantity of soil NPK (Table 3).

2.4 Leaf mineral composition

The concentration of macro and micronutrients (N, P, K, Ca, Mg, Na, Fe, Mn, Cu and Zn) in the leaves of black locust trees differed significantly under impact of two irrigation treatments. These concentrations in the leaves of sewage irrigated trees were about 1.5 times higher than those of well water irragation. However, irrigation with municipal sewage did not result in toxicity to minerals of leaves (Salardini, 1992). The concentration of leaf minerals ranked from greatest to least as Ca > N > K > Mg > P > Na > Fe > Mn > Zn > Cu. Fe, Mn, Zn and

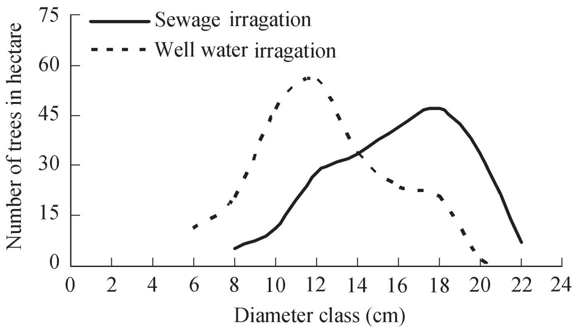

Fig. 1 Distribution of diameter classes of *R. pseudoacacia* trees in two study stands.

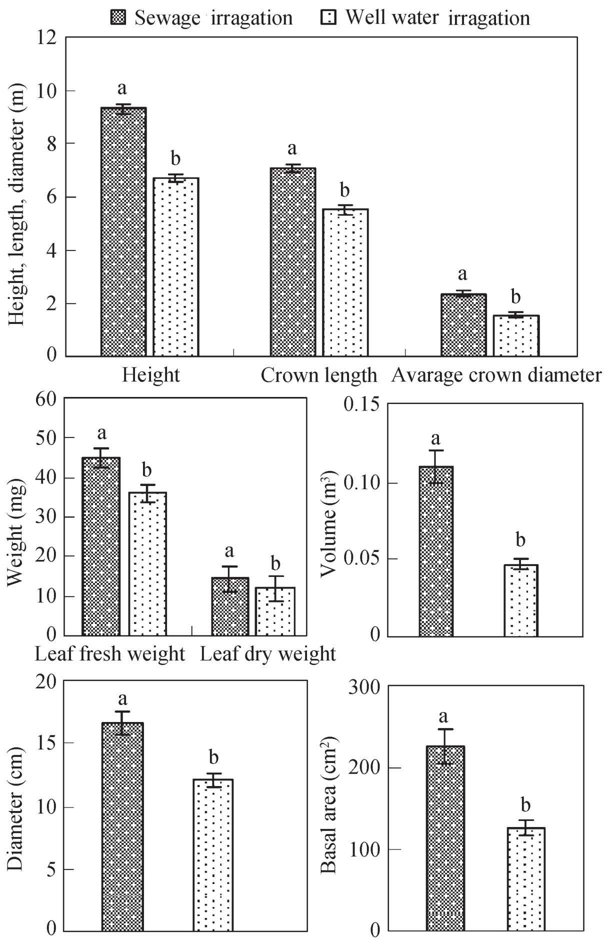

Fig. 2 Effect of municipal sewage application on growth of *R. pseudoacacia* trees, error bars are ± SE.

Table 4 Effect of municipal sewage irrigation on the leaf mineral composition of *R. pseudoacacia* trees

Treatment	T_1	T_2	*P*-value	Critical value**
N (g/kg)	30.74 ± 0.98 a*	26.80 ± 2.03 b	< 0.05	5–30
P (g/kg)	1.04 ± 0.024 a	0.757 ± 0.022 b	< 0.01	1–5
K (g/kg)	8.12 ± 1.05 a	5.73 ± 0.739 b	< 0.01	3–30
Ca (g/kg)	31.57 ± 1.74 a	27.48 ± 1.80 b	< 0.05	10–40
Mg (g/kg)	3.38 ± 0.53 a	2.38 ± 0.097 b	< 0.01	1–7
Na (g/kg)	0.126 ± 0.025 a	0.083 ± 0.021 b	< 0.05	–
Fe (mg/kg)	110.00 ± 9.12 a	91.87 ± 7.18 b	< 0.05	40–200
Zn (mg/kg)	30.62 ± 5.99 a	20.62 ± 2.60 b	< 0.05	10–100
Mn (mg/kg)	46.56 ± 8.98 a	31.56 ± 2.77 b	< 0.05	20–100
Cu (mg/kg)	4.87 ± 0.77 a	2.81 ± 0.239 b	< 0.01	2–20
Pb (mg/kg)	ND	ND		
Ni (mg/kg)	ND	ND		
Cr (mg/kg)	ND	ND		

ND: not detected; T_1: municipal sewage irragation; T_2: well water irragation. * Values are mean of four replications ± SD; different letters in row indicate significant difference between T_1 and T_2.
** Salardini, 1992.

Cu are micronutrients and heavy metals that plants need to them in low values. Ni, Cr and Pb were not detected in leaf samples (Table 4).

2.5 Relationships between mineral concentrations in soil and tree leaf

Linear regression analysis was used to evaluate the relationships between mineral concentrations in soil and leaf of black locust trees. These relationships are presented in Figs. 3 and 4. The results showed that the concentrations of leaf macro and micronutrients were positively correlated with those of soil. Nevertheless, only the Na and P contents of leaves were well correlated with those of soil (R^2 = 0.91; R^2 = 0.90, respectively), while linear regression analysis between the other mineral contents of leaves and their respective contents in soil presented lower R^2 values.

3 Discussion

The analysis of water samples shows that pH, EC, NO_3^--N, PO_4^{3-}-P, K, Na and Cu are well within the limits as per the standard prescribed for land disposal and should not pose any serious hazard according to threshold values of WHO (Hach, 2002). However, the contents of NH_4^+-N, Ca and Pb of municipal sewage and well water and Mg, Zn, Mn, Fe, Ni and Cr of municipal sewage were on the higher level (Table 1), which could prove to be toxic to soil and plant. The high concentration of NH_4^+-N, Ca and Pb in well water and sewage may be respectively due to the excessive use of fertilizers, calciferous soil and air pollution in the studied area. The elevated levels of heavy metals in municipal sewage may be due to effluents discharged from some little industrial units such as the batteries and paint. Since high quantities of some elements were traced in some of water samples, there is a matter of concern that further increase in their contents may be hazardous and hence the influence of these metals would need to be considered.

Based on the differences of soil characteristics (Table 2), continuous application of municipal sewage influenced the soil physico-chemical properties (Mathan, 1994). The suitability of soils for receiving sewage without deterioration varies widely, depending on their infiltration capacity, permeability, cation exchange capacities, phosphorus adsorption capacity, texture, structure, and type of clay

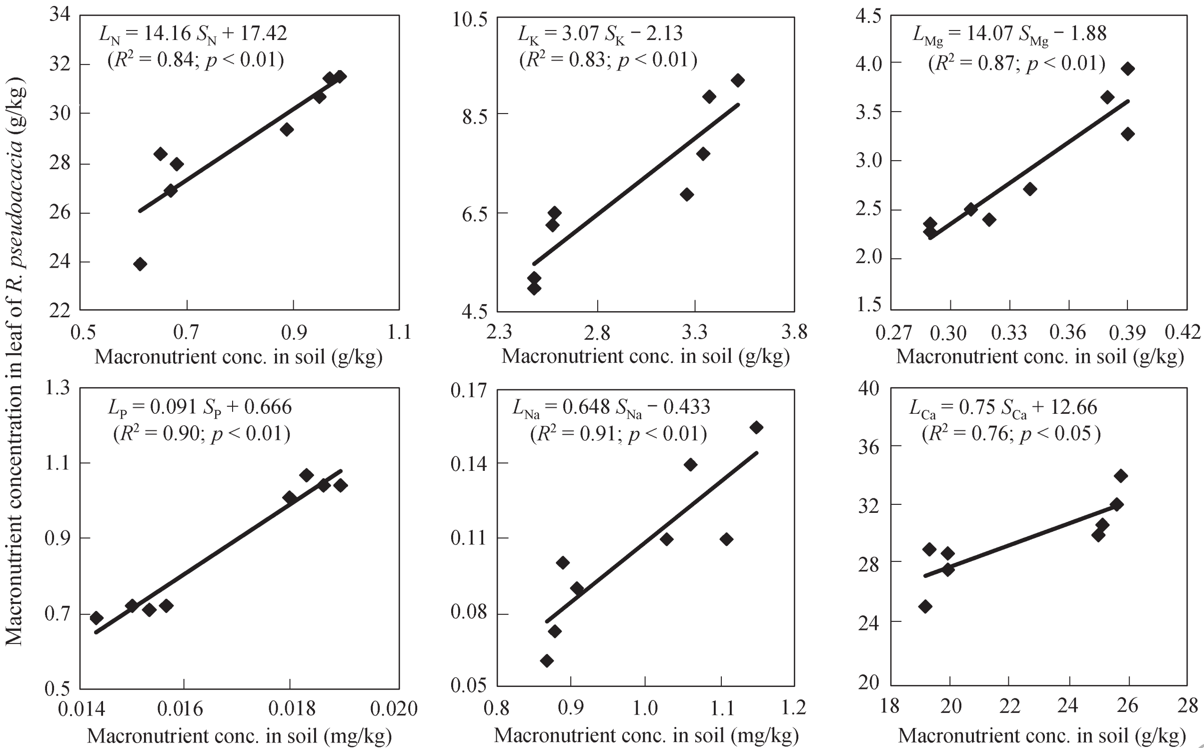

Fig. 3 Relationships between macronutrient concentration in leaf of *R. pseudoacacia* trees and in soil. *L*: macronutrient concentration in leaf (g/kg); *S*: macronutrient concentration in soil (except P and Na in mg/kg and others are in g/kg).

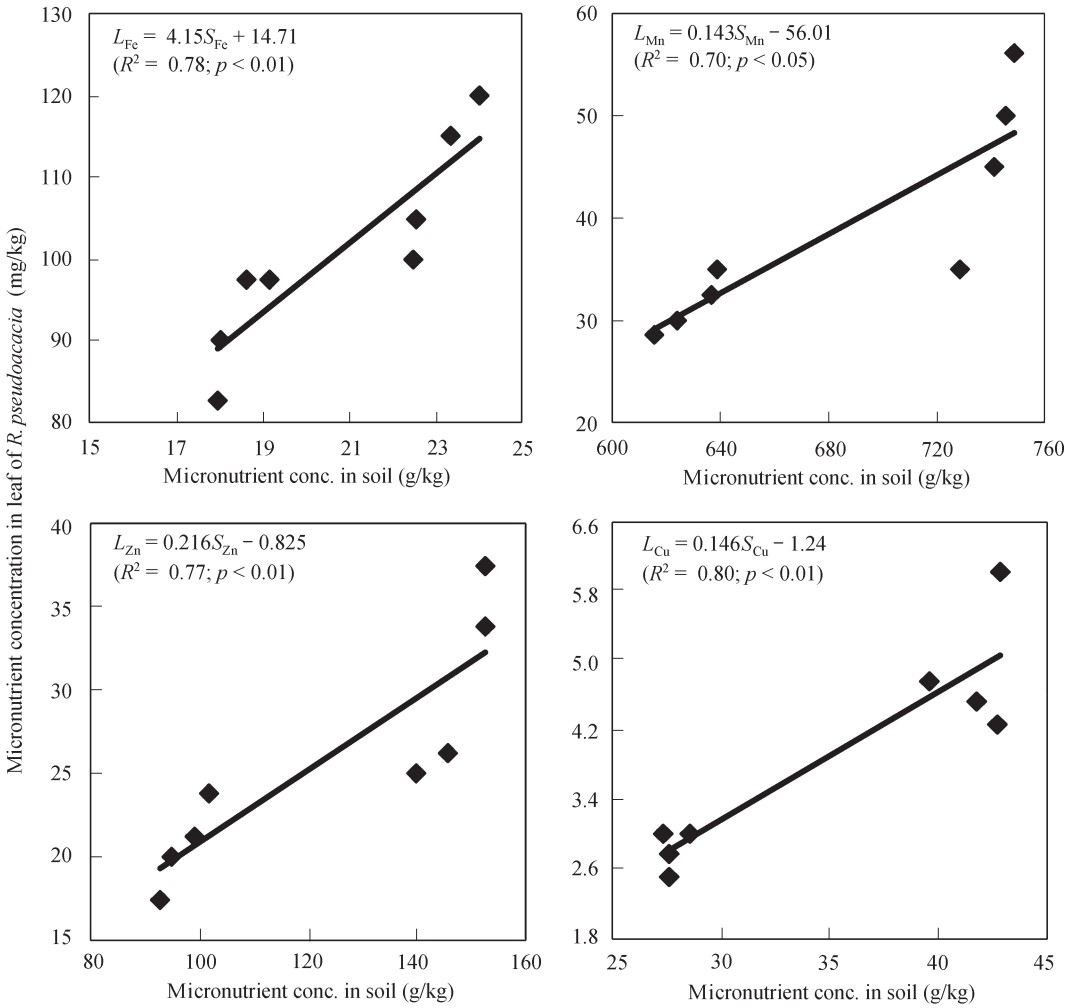

Fig. 4 Relationships between micronutrient concentration in leaf of *R. pseudoacacia* trees and that in soil. *L*: micronutrient concentration in leaf (mg/kg); *S*: micronutrient concentration in soil (except Fe in g/kg and others are in mg/kg).

mineral (Ivan and Earl, 1972). In this study, significant increase in pH, EC, and SOC content of the sewage irrigated soil may have been due to municipal sewage application (Ramirez-Fuentes *et al*., 2002).

Increased soil availability of nutrients in sewage irrigation might be due to their addition through municipal sewage in spite of their high uptake by the growing plants (Meli *et al*., 2002; Zhang *et al*., 2008). The addition of nutrients was beneficial in nutrient deficient soil of the arid region. Evidently, while the additional nutrients can be a bonus as additional fertilizer, excess nutrients can have an adverse effect through increase the vulnerability of the plants towards pathogens and therefore needs the reduction before application (Arora *et al*., 1985; Toze, 2006). The concentrations of heavy metals (Ni, Cr and Pb) were also higher in all depths of sewage irrigated soil compared to those of well water irrigated soil. The effects of sewage irrigation on soil heavy metal accumulation depend on various factors such as concentration of heavy metals of sewage, the period of sewage application and soil properties (pH, texture, organic matter) (Rattan *et al*., 2005). Among the soil elements only Pb and Ni in some soil samples exceeded the toxicity limit according to Salardini (1992). Generally, 10 to 50 years is needed so that the soil heavy metals levels precede the standard levels (Smith *et al*., 1996). Because of the high concentration of Pb in all soil and water samples, it can be predicted that besides the municipal sewage, Pb probably has been added to the water and soil from other sources such as air pollution.

In accord with the findings obtained later, where an increase in growth of *Olea europaea* and *pinus eldarica* trees due to irrigation with municipal sewage has been reported by Aghabarati *et al*. (2008) and Salehi *et al*. (2008) respectively, greater growth and biomass production of trees under sewage treatment may be linked to the sufficient availability of water and better status of nutrients in soil (Larchevêque *et al*., 2006). Positive correlation between diameter at breast height, height and volume of trees with quantity of soil NPK (Table 3) also supports this inference. Since municipal sewage contains plant nutrients and organic matter, it may improve the properties of soil for increase in growth and biomass production (Guo *et al*., 2002; Lopez *et al*., 2006). The increase in growth indicates that sewage application influenced the physiological processes, facilitated early leaf initiation and resulted in a net increase in the number of leaves. An increase in leaves could have captured more solar energy for metabolic use, fixed more CO_2, and produced greater photosynthates, and growth. This hypothesis is also supported by Ceulemans *et al*. (1993) and Myers *et al*. (1996). High leaf biomass in municipal sewage irrigated trees compared to well water is obviously due to the addition of nitrogen and phosphorus through municipal sewage irragation (Bhati and Singh, 2003).

Marked difference in nutrients of tree leaf (Table 4) may be due to the increase of nutrients through municipal sewage (Meli *et al*., 2002). This result is in agreement with Singh and Bhati (2005) and Aghabarati *et al*. (2008), where substantially greater concentration of minerals were observed in leaf of *Dalbergia sissoo* seedlings and *O. europaea* trees irrigated with municipal sewage compared to control. However, Guo *et al*. (2002) had also suggested a decrease of Mg and Ca concentration in leaf of eucalypt trees treated by municipal sewage compared to control. Ni, Cr and Pb were not detected in leaf samples which may be due to the low dynamic of heavy toxic metals, whereas it was likely accumulated in lower parts of the plant, such as root and stem. Nevertheless, Madejoón *et al*. (2006) reported the presence of some heavy metals in leaf of olive and holm oak trees. In fact, the quantity of element absorption using plant depends upon many factors including the total quantity of the elements applied through sewage application, soil properties, and type of plant (Bozkurt and Yarilga, 2003; Sharma *et al*., 2007).

Significant positive correlations were found between the concentrations of nutrients in soil and tree leaf suggest that the trend of mineral concentration in plants would be a function of mineral content in soil and also depended on their uptake by plants (Rattan *et al*., 2005). Similar trends were also demonstrated by Wang and Klinka (1997) and Gascó and Lobo (2007), where positive correlations were reported between quantity of NPK and Mg in needle of *Picea glauca* and Na, Ca, Mg, Zn and Cu in leaf of olive trees with their respective contents in soil. Nevertheless, Sharma *et al*. (2007) suggested that correlation between mineral concentrations in soil and plant varied between different seasons. Higher R^2 values for some elements (Na and P) may be due to better absorption of these elements using plant under the influence of some soil and plant factors.

4 Conclusions

The present study concludes that the irrigation by municipal sewage had a positive influence on the growth and production of *R. pseudoacacia* trees. Furthermore, the results from the area where municipal sewage is being used for about 15 years showed the enrichment of soil with nutrients without their excessive accumulation in soil and plant. In fact, the application of municipal sewage facilitated the availability of valuable essential nutrients and water in soil. Hence, it can be recommended that the use of such sewage can effectively increase water resources for irrigation of trees in dry area and its aesthetic and environmental benefits in suburban area.

Moreover, there are factors that need to be considered, for example the presence of some heavy metals and pathogens in applied sewage. In this study some water and soil heavy metals exceeded the toxicity limit that may pose potential environmental and health risks in the long-term. Thereby, regulations about the utilization of sewage in irrigation should consider to minimize the risk of negative effects to ecosystem health. This can be controlled by avoiding toxic elements from entering the municipal sewage and continued monitoring or treatment of sewage before it is put into disposal channel for irrigation.

Acknowledgments

This project was supported by the Tarbiat Modares University Research Fundation. Authors are grateful to Forestry Department of the Tarbiat Modares University for technical and scientific assistance and Shahr-e-Ray Municipality for its support on field assistance of this research.

References

Aghabarati A, Hosseini S M, Esmaili A, Maralian H, 2008. Growth and mineral accumulation in *Olea europaea* L. trees irrigated with municipal effluent. *Research Journal of Environmental Sciences*, 2(4): 281–290.

APHA, 1992. Standard methods for the examination of water and wastewater (16th ed). APHA, AWWA and WPCF.

Arora B R, Azad A S, Singh B, Sekhon G S, 1985. Pollution potential of municipal waste water of Ludhina, Punjab. *Environmental Journal of Ecology*, 12: 1–7.

Bhati M, Singh G, 2003. Growth and mineral accumulation in *Eucalyptus camaldulensis* seedlings irrigated with mixed industrial effluents. *Bioresource Technology*, 88: 221–228.

Bouyoucos G J, 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal*, 54: 464–465.

Bozkurt M A, Yarilga T, 2003. The effects of waste water sludge applications on the yield, growth, nutrition and heavy metal accumulation in apple trees growing in dry conditions. *Turkish Journal of Agriculture and Forestry*, 27: 285–292.

Ceulemans R J, Pontailler F M, Guittet J, 1993. Leaf allometry in young poplar stands: reliability of leaf area index estimation, site and clone effects. *Biomass and Bioenergy*, 4: 769–776.

Emongor V E, Ramolemana G M, 2004. Treated waste water effluent (water) potential to be used for horticultural production in Botswana. *Physics and Chemistry of the Earth*, 29: 1101–1108.

Gascó G, Lobo M C, 2007. Composition of Spanish waste water sludge and effects on treated soil and olive trees. *Waste Management*, 27(11): 1494–1500.

Gerhart V J, Kane R, Glenn E P, 2006. Recycling industrial saline wastewater for landscape irrigation in a desert urban area. *Journal of Arid Environments*, 67: 473–486.

Guo L B, Sims R E H, Horne D J, 2002. Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand. I: biomass and nutrient accumulation. *Bioresource Technology*, 85: 273–283.

Gupta A P, Narwal R P, Antil R S, 1998. Sewer water composition and its effect on soil properties. *Bioresource Technology*, 65: 171–173.

Habibi K H, 1992. Forest Pedology. Tehran, Iran: Tehran University Press. 424.

Hach C, 2002. Water Analysis Handbook. Loveland, Colorado, USA. WHO, 61–62.

Ivan F S, Earl E A, 1972. Soil limitations for disposal of municipal waste waters. Michigan State University Research Report 195: 54.

Jackson M L, 1973. Soil Chemical Analysis. Prentice Hall of India Private Ltd., New Delhi.

Jayaraman K, 2000. A Statistical Manual for Forestry Research. FORESPA Publication, 240.

Larchevêque M, Ballini C, Korboulewsky N, Monts N, 2006. The use of compost in afforestation of Mediterranean areas: Effects on soil properties and young tree seedlings. *Science of the Total Environment*, 369: 220–230.

Letacon F, 1969. An original method for leaf sampling. R.F.F., 3: 196–197.

Lindaman H R, 1992. Analysis of Variance in Experimental Design. New York: Springer-Verlag.

Lopez A, Pollice A, Lonigro A, Masi S, Palese A M, Cirelli G L, Toscano A, Passino R, 2006. Agricultural wastewater reuse in southern Italy. *Desalination*, 187: 323–334.

Madejón P, Marañón T, Murillo J M, 2006. Biomonitoring of trace elements in the leaves and fruits of wild olive and holm oak trees. *Science of the Total Environment*, 355: 187–203.

Mathan K K, 1994. Studies on the influence of long-term municipal sewage-effluent irrigation on soil physical properties. *Bioresource Technology*, 48: 275–276.

Meli S, Porto M, Belligno A, Bufo S A, Mazzatura A, Scopa A, 2002. Influence of irrigation with lagooned urban wastewater on chemical and microbiological soil parameters in a citrus orchard under Mediterranean condition. *Science of the Total Environment*, 285: 69–77.

Mossadegh A, 1993. Afforestation and Forest Nursery. Tehran, Iran: Tehran University Press, 516.

Myers B J, Theiveyanath S O, Brian N O, Bond W J, 1996. Growth and water use of *Eucalyptus grandis* and *Pinus radiata* plantations irrigated with effluent. *Tree Physiology*, 16: 211–219.

Nelson D W, Sommers L E, 1996. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis: Part 3. Chemical Methods (Bigham J M, ed.). Madison: SSSA. 961–1010.

Olsen S R, Cole C V, Watanabe F S, Dean L A, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. In: USDA Circ. 939, United States Department of Agriculture, Washington D.C.

OMA, 1990. Official Methods of Analysis (15th ed). Association of Official Analytical Chemists, Arlington, Virginia, USA.

Pelosi M K, Sandifer T M, 2003. Elementary statistics: from discovery to decision. John Willey & Sons, INC. 793.

Ramirez-Fuentes E, Lucho-Constantino C, Escamilla-Silva E, Dendooven L, 2002. Characteristics and carbon and nitrogen dynamics in soil irrigated with waste water for different lengths of time. *Bioresource Technology*, 85: 179–187.

Rattan R K, Datta S P, Chhonkar P K, Suribabu K, Singh A K, 2005. Long-term impact of irrigation with waste water effluents on heavy metal content in soils, crops and groundwater – A case study. *Agriculture, Ecosystems and Environment*, 109: 310–322.

Salardini A, 1992. Soil Fertility. Tehran, Iran: Tehran University Press. 440.

Salehi A, Tabari M, Mohammadi J, Ali-Arab A R, 2008. Effect of irrigation with municipal effluent on soil and growth of *pinus eldarica* Medw. trees. *Iranian Journal of Forest and Poplar Research*, 16(2): 186–196.

Sharma A, Ashwath N, 2006. Land disposal of municipal effluents: Importance of choosing agroforestry systems. *Desalination*, 187: 361–374.

Sharma R K, Agrawal M, Marshall F, 2007. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotoxicology and Environmental Safety*, 66: 258–266.

Singh G, Bhati M, 2005. Growth of *Dalbergia sissoo* in desert regions of western India using municipal effluent and the subsequent changes in soil and plant chemistry. *Bioresource Technology*, 96: 1019–1028.

Singh R P, Agrawal M, 2008. Potential benefits and risks of land application of sewage sludge. *Waste Management*, 28(2): 347–358.

Smith C J, Hopmans P, Cook F J, 1996. Accumulation of Cr, Pb, Cu, Ni, Zn and Cd in soil following irrigation with treated urban effluent in Australia. *Environmental Pollution*, 94: 317–323.

Stewart H T L, Flinn D W, 1984. Establishment and early growth of trees irrigated with wastewater at four sites in Victoria, Australia. *Forest Ecology and Management*, 8: 243–256.

Toze S, 2006. Reuse of effluent water-benefits and risks. *Agricultural Water Management*, 80: 147–159.

Wang J R, Klinka K, 1997. White spruce foliar nutrient concentration in relation to tree growth and soil nutrient amounts. *Forest Ecology and Management*, 1: 89–99.

Yadav R K, Goyal B, Sharma R K, Dubey S K, Minhas P S, 2002. Post-irrigation impact of domestic sewage effluent on composition of soils, crops and ground water –A case study. *Environment International*, 28(6): 481–486.

Zhang Y L, Dai J L, Wang R Q, Zhang J, 2008. Effects of long-term sewage irrigation on agricultural soil microbial structural and functional characterizations in Shandong, China. *European Journal of Soil Biology*, 44: 84–91.

Zobeiri M, 1994. Forest Inventory. Tehran, Iran: Tehran University Press. 401.