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ORIGINAL ARTICLE

Survival, growth and mineral accumulation in ash *Fraxinus excelsior* L. seedlings irrigated with water treatment effluent

Bahareh Selahvarzi, Seyed Mohsen Hosseini ✉

Tarbiat Modares University, Faculty of Natural Resources, Department of Forestry, P.O. Box 14115-111, Tehran, Iran, phone: 09111213898, fax: 01226253499, e-mail: hosseini@modares.ac.ir

Abstract

A pot experiment was carried out to study the effect of irrigation with water treatment effluent on the growth and chemical constituents of ash seedlings *Fraxinus excelsior* L. according as soil chemical properties. This research was conducted at the site near to the Eastern Tehran water treatment plant. Ash seedling were planted in pots in three score rows After measuring their primary dimensions, the seedlings were irrigated with water treatment effluent, well water and water mix (50% well water + 50% water treatment effluent) for the period of April–October 2010. Three replications were considered for each of the score rows. During the entire period of observations, survival and growth parameters of three random seedling samples from each treatment were measured once in two months until the end of the growth season (October 2010). Observations included seedling height, collar diameter and survival. Application of water treatment effluent, well water and water mix indicated same seedling survival but water treatment effluent was superior than other treatments in improving seedling growth parameters (height, collar diameter and biomass dry weight) as well as it brought about the highest concentration of N, P, K and Mg in plant parts, when compared with mix water and well water treatments.

Key words

Fraxinus excelsior seedlings**,** effluent, green space, growth, irrigation, plantation

Introduction

In arid and semi-arid countries, water has become a scarce resource, and any source of water, which might be used economically and effectively to promote further development should be considered. Rapid increase of human population and the industrial growth have led to using low quality water, such as drainage and saline water as well as wastewater for irrigation. Irrigation of forest tree species grown for fuel and timber production with wastewater is an approach which helps to overcome health hazards associated with sewage farming. Establishment of green belts around cities which consist of forest trees under wastewater irrigation helps to revive ecological balance and improves environmental conditions by self-treatment of wastewater through the application of forest irrigation. The use of primary and secondary effluents in irrigation can improve both soil quality and plant growth since effluents are considered as natural conditioners because of their nutrient ele-

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ments and organic matter. However, the direct application of wastewater on agricultural land is limited due to the extent of wastewater contamination with heavy metals, toxic organic chemicals and pathogens (EL-Nennah et al. 1982; Abulroos et al. 1996; Salem et al. 2000; Sebastiani et al. 2004; EL-Sayed 2005; Singh and Bhati 2005; Ali et al. 2010).

Iran is a part of world's arid regions and has encountered acute crises owing to the population raise and an increased need for water resources (Tabatabaei 1998). It is noteworthy that thousands of liters of domestic, industrial and hospital effluents flow daily from Tehran metropolitan area and influence underground water resources (Tajrishi 1998). On the other hand, unplanned expansion of Tehran and its air pollution make it unavoidable to increase the green space within and around the city. In reality, creation of urban green space and a green belt around any city can play an effective role in air purification and climate health. Since the lack of water is a limiting factor for development of green space, therefore, the use of effluent may be suitable (Torabian and Hashemi 1999). The use of waste water in growing woodlots is a viable option for economic disposal of wastewater. Additional benefits include biomass production and sequestration of excess minerals in the plant system (Neilson et al. 1989). Management of wastewater irrigation should consider wastewater nutrient content, specific crop nutrient requirement, soil nutrient content and other soil fertility parameters (Mohammad and Ayadi 2004). The decision about application of effluent should be made in view of water, soil, plant features and characteristics of each location environment (Naghshinehpour 1998).

In the country several studies have been up to date conducted on the effect of effluent on soil, agricultural crops and hardwood trees, but not on the effect of water treatment plant effluent on hardwood seedlings. For this reason, the current research was undertaken to determine the effect of irrigation with Eastern Tehran water treatment plant effluents (being produced each day at a level from 15000 m^3 to 25000 m^3), on ash *F. excelsior* L. seedlings. *Fraxinus excelsior* is one of the most important species in urban green space in Iran. The ash occurs on a wide range of soil types. This is a large deciduous tree growing to 20–35 m (exceptionally to 46 m) of height, with trunk diameter up to 2 m (exceptionally to 3.5 m) and tall, domed crown. It can survive well near smoke and pollution being a good urban dweller.

Material and methods

Study area

The field study took place at a site near to the Eastern Tehran water treatment plant (Northeast of Tehran, latitude 51.37' N, longitude 35.47' E, elevation 1548 m a.s.l.). Mean annual precipitation is 400.1 mm, with maximum rainfalls during the winter. Maximum and minimum mean monthly temperatures are 33.6ºC in July and –1.3ºC in January, and average annual temperature is 15.3ºC. The warmest month is July and the coldest – January. The water treatment plant purifies entrance water in chemical way and produces 15,000 m^3 to 25,000 m^3 effluents each day.

Sampling method

One-year-old ash *F. excelsior* seedlings were planted in pots in three score rows at the site by the Eastern Tehran water treatment plant. After measuring their primary dimensions, the seedlings were irrigated with water treatment effluent, well water and mix water (50% well water + 50% water treatment effluent) in the period of April 2010 – October 2010. Each of three score rows included three replications and each replication included 20 seedlings. Each pot was irrigated with about 200 ml of water treatment effluent or well water or mix water) every day. Until the end of the vegetation season there were assessed the parameters such as survival, height and collar diameter of seedlings with selection three random samples.

Water, soil and plant samples were taken from all rows. The samples of water treatment effluent, well water and mix water were collected from the water treatment plant every month from April 2010 to October 2010. The collection provided nine samples of water treatment effluent each month (three days and each day three samples, at 6 hour intervals: at 7 am, 1 pm and 7 pm). Altogether, there were 162 samples, which included 54 (9×6) samples of effluent, 54 (9×6) samples of well water and 54 (9×6) samples of mix water for study period.. Three acid-washed polyethylene bottles of 100 ml capacity were immersed one by one at an interval of 15 sec to avoid microbial utilization of heavy metals. Soil samples were collected from April 2010 to October 2010. Three soil samples from seedling root zone (0–15 cm down) in each replication (3 × 3 × 3 = 27) were selected. In each replication, three ash seedlings (3 × 3 × 3 = 27) were chosen and sampled during August and September. Samples of leaves, stems and roots were separated from seedlings and washed (approximately for 10 sec) with a solution of phosphate-free detergent, then with a 0.1 NHCl solution and finally with distilled water. The plant samples were dried at 70º C, ground and passed through a 500 µM stainless steel sieve (Jackson 1973).

Laboratory and data analyses

Water samples were brought to the laboratory, filtered through Whatman No. 42 filter paper and stored at 4º C (OMA 1990). Each sample was analyzed for electrical eonductivity (EC) and macro- and micronutrient concentration using standard procedures (OMA 1990). Total alkalinity was determined by the titration method by OMA (1990). K and Mg contents were determined with atomic absorption spectrophotometry (AAS). Nitrogen (N) and phosphorus (P) were analyzed calorimetrically according to Evenhuis (1976), and Murphy and Riley (1962). Soil samples were transported to the laboratory, oven-dried at 40º C and crushed to pass through a 2 mm sieve. Electrical conductivity (EC) and soil organic matter (OM) were determined using standard procedures (Jackson 1973). For determination of macro and micronutrients, soil samples were extracted in the solution of ammonium acetate and sodium salt of diethylenetriaminepentaacetic acid (DTPA). Calcium (Ca) and magnesium (Mg) were estimated in absorption mode and potassium (K) in emission mode using a double beam atomic absorption spectrophotometer (model-3110, Perkin-Elmer) (Lindsay and Norvell 1978). Available nitrogen was determined with Kjeldhal's method. Extractable phosphorus was determined by Olsen's extraction method (Jackson 1973). Samples of seedlings were brought to the laboratory and magnesium (Mg) was estimated in absorption mode and potassium (K) in emission mode using a double beam atomic absorption spectrophotometer (model 3110, Perkin-Elmer). Measurement of P content in plants was performed after a wet digestion using UV-vis spectrophotometer (Systronix model 117) at 490 and 420 nm. Data were statistically analyzed using SPSS software. Initially, normal distribution of data was tested using the Kolmogorove-Smirnov test. Variance homogeneity of compared groups was tested using the Levene test. For statistical analyses of normally distributed data there was used one-way ANOVA and Tukey's HSD. Non-normal data were tested with the Kruskal – Wallis one-way analysis of variance and the Mann – Whitney – U test.

Results

Water

The results showed that electrical conductivity and contents of K, Mg, N and P in water treatment effluent were significantly greater ($p < 0.01$) than those in well water (Tab. 1).

Tab. 1. Main characteristics of water treatment effluent and well water (mean ±SE)

Quality Parameters	Municipal effluent	Well water
EC ms/cm)	0.33 ± 0.004^{a}	0.32 ± 0.004^{b}
K (mg/L)	3.28 ± 0.38^{a}	2.12 ± 0.12^{b}
Mg (mg/L)	17.25 ± 1.83^{a}	11.45 ± 0.85^{b}
N (mg/L)	2.23 ± 0.19^{a}	0.21 ± 0.04^{b}
P (mg/L)	4.43 ± 0.62^{a}	0.47 ± 0.13^{b}

Means with different superscripts in columns are significantly different ($p < 0.01$).

Soil

Multiple comparison performed with Tukey's HSD indicated that 6-month application of water treatment effluent resulted in increase of soil (0–15 cm layer) EC, OM concentration, as well as N, P, K and Mg contents when compared with those in soil treated with mix water or well water ($p < 0.01$, Tab. 2).

Seedlings

The survival of seedlings did not differ ($p > 0.05$) among the treatments. The results showed that the height, collar diameter, leaf wet and dry biomass and stem and roots of ash seedlings irrigated with water treatment effluent for 6 months were significantly greater ($p < 0.01$)

Tab. 2. Effect of 6-month application of water treatment effluent on physicochemical properties of soil

Quality Parameters	Soil Sampling Period								
	First			Second			Third		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
EC (ds/m)	0.19 ± 0.0[a]	0.17 ± 0.1[a]	0.11 ± 0.0[b]	0.20 ± 0.1[a]	0.18 ± 0.1[a]	0.13 ± 0.0[b]	0.22 ± 0.2[a]	0.20 ± 0.1[a]	0.15 ± 0.1[b]
OM (%)	0.44 ± 0.1[a]	0.38 ± 0.1[a]	0.24 ± 0.1[b]	0.81 ± 0.2[a]	0.48 ± 0.3[b]	0.34 ± 0.3[c]	1.2 ± 0.2[a]	1.1 ± 0.0[a]	0.55 ± 0.4[b]
Mg (g/kg)	2.5 ± 0.0[a]	2.5 ± 0.2[a]	2.4 ± 0.1[a]	2.9 ± 0.1[a]	2.7 ± 0.1[a]	2.2 ± 0.1[b]	3.5 ± 0.2[a]	2.9 ± 0.1[ab]	2.3 ± 0.3[b]
K (g/kg)	0.11 ± 0.0[a]	0.10 ± 0.0[a]	0.10 ± 0.0[a]	0.23 ± 0.1[a]	0.13 ± 0.1[ab]	0.08 ± 0.0[b]	0.16 ± 0.1[a]	0.13 ± 0.1[ab]	0.07 ± 0.0[b]
N (mg/kg)	0.05 ± 0.0[a]	0.04 ± 0.0[a]	0.04 ± 0.0[a]	0.07 ± 0.0[a]	0.06 ± 0.1[ab]	0.05 ± 0.0[b]	0.11 ± 0.1[a]	0.09 ± 0.2[ab]	0.05 ± 0.0[b]
P (mg/kg)	30.5 ± 2.9[a]	28.4 ± 5.1[a]	23.5 ± 5.9[a]	35.9 ± 1.6[a]	27.9 ± 2.9[a]	16.3 ± 0.7[b]	37.2 ± 3.5[a]	34.8 ± 0.6[a]	12.1 ± 1.8[b]

T_1 – irrigation with water treatment effluent; T_2 – irrigation with mix water; T_3 – irrigation with well water. Values are means of three replications ± SE. Means with different superscripts in columns are significantly different ($p < 0.01$).

than in seedlings irrigated with mix water or well water (Fig. 1).

The survival, mean height, mean collar diameter of seedlings and mean dry weight of the total number of leaves, stem and roots per seedling irrigated with water treatment effluent weregreater than those of the seedlings irrigated with well water.

Mineral element concentrations in seedlings differed significantly ($p < 0.01$) according as both seedling parts and irrigation treatments applied. N, P, K and Mg concentrations were higher in the seedlings irrigated with water treatment effluent than those in seedlings treated with mix water or well water (Fig. 2).

Discussion

Soil mineral parameters

Water treatment effluent irrigation significantly increased electrical eonductivity, soil organic matter as well as K, N, P and Mg contents in the topsoil layer (0–15 cm). The increase in soil EC may have been due to its alkaline nature and salt concentration in effluent (Mitra and Gupta 1999). Mohammad and Mazahreh (2003) stated that the increase of EC in soil irrigated with wastewater when compared with that of soil irrigated with potable water (well water) was caused by high contents of total dissolved solids (TDS) in wastewater. Soil organic matter (SOM) significantly increased with the application of municipal effluent irrigation which can be attributed directly to the content of nutrients and organic compounds in the municipal effluent applied. Similar increase of organic matter content was also noted by Walker and Lin (2007) and Walker (2006) in soil irrigated with wastewater. Vazquezmonitel et al. (1996) found no positive effect of wastewater irrigation on soil organic matter whereas other researchers reported a soil organic matter increase as a result of irrigation with wastewater (Mancino and Pepper 1992). Availability of NH4-N, NO_3-N, PO_4-P, K, Ca and Mg was greater in soil irrigated with municipal effluent when compared to that irrigated with well water, suggesting the ameliorative effect through absorption and accumulation in tree parts (Singh and Bahati 2005). Baddesha et al. (1985) also reported that irrigation of soil under eucalyptus plantation with sewage water increased concentrations of macro- and micronutrients.

Several researchers reported accumulation of N, P and K in soil with treated with wastewater, and this was attributed to initial contents of these nutrients in wastewater applied (Monnett et al. 1996). Presented results agree with those reported by Day et al. (1979) and Mohammad and Mazahreh (2003) who found that extractable phosphorus was higher in soil irrigated with wastewater than

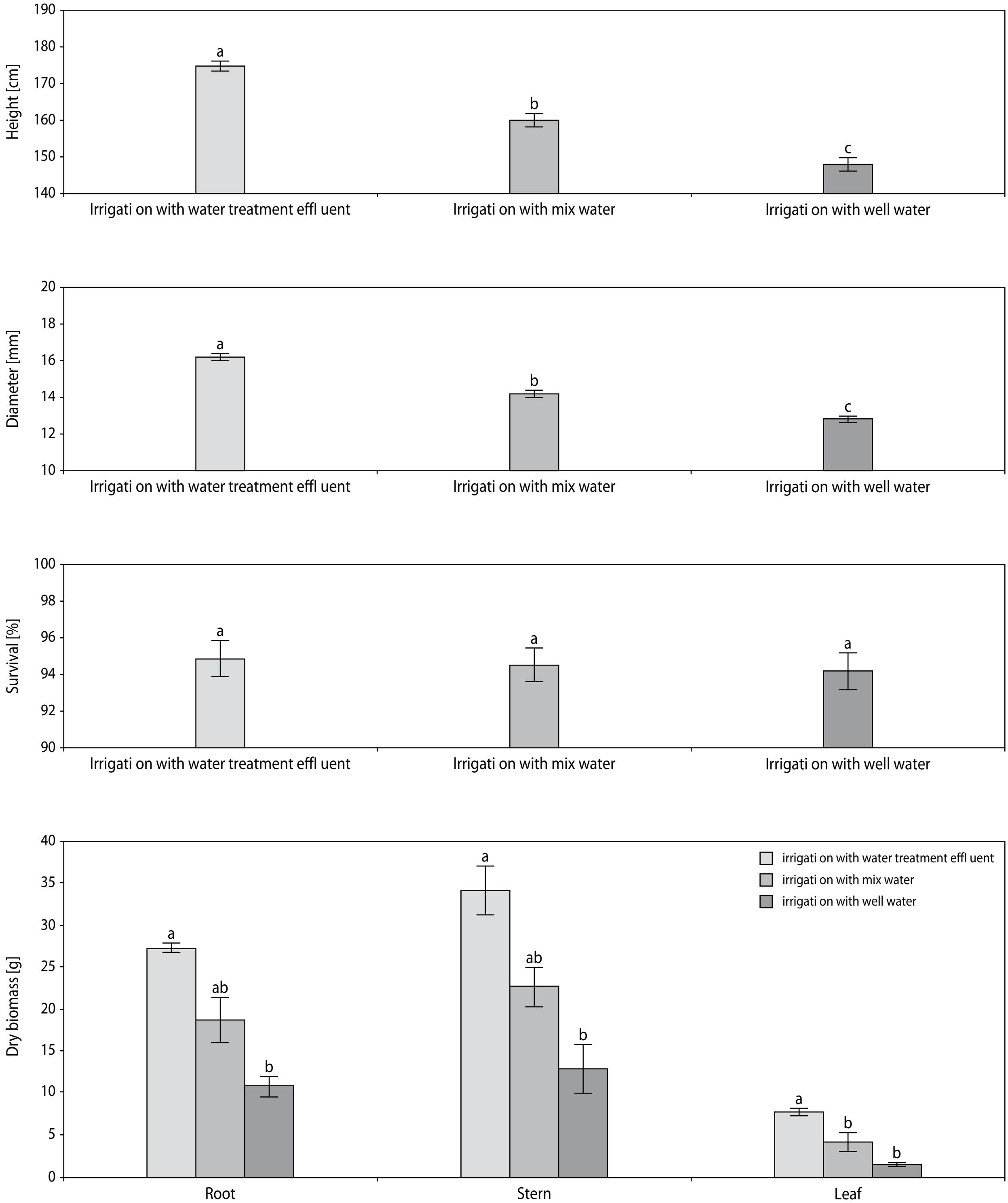

Fig. 1. Comparison of parameters measured in *Fraxinus excelsior* seedlings in three differently irrigated areas. Ddifferent superscripts indicate significant differences ($p < 0.01$)

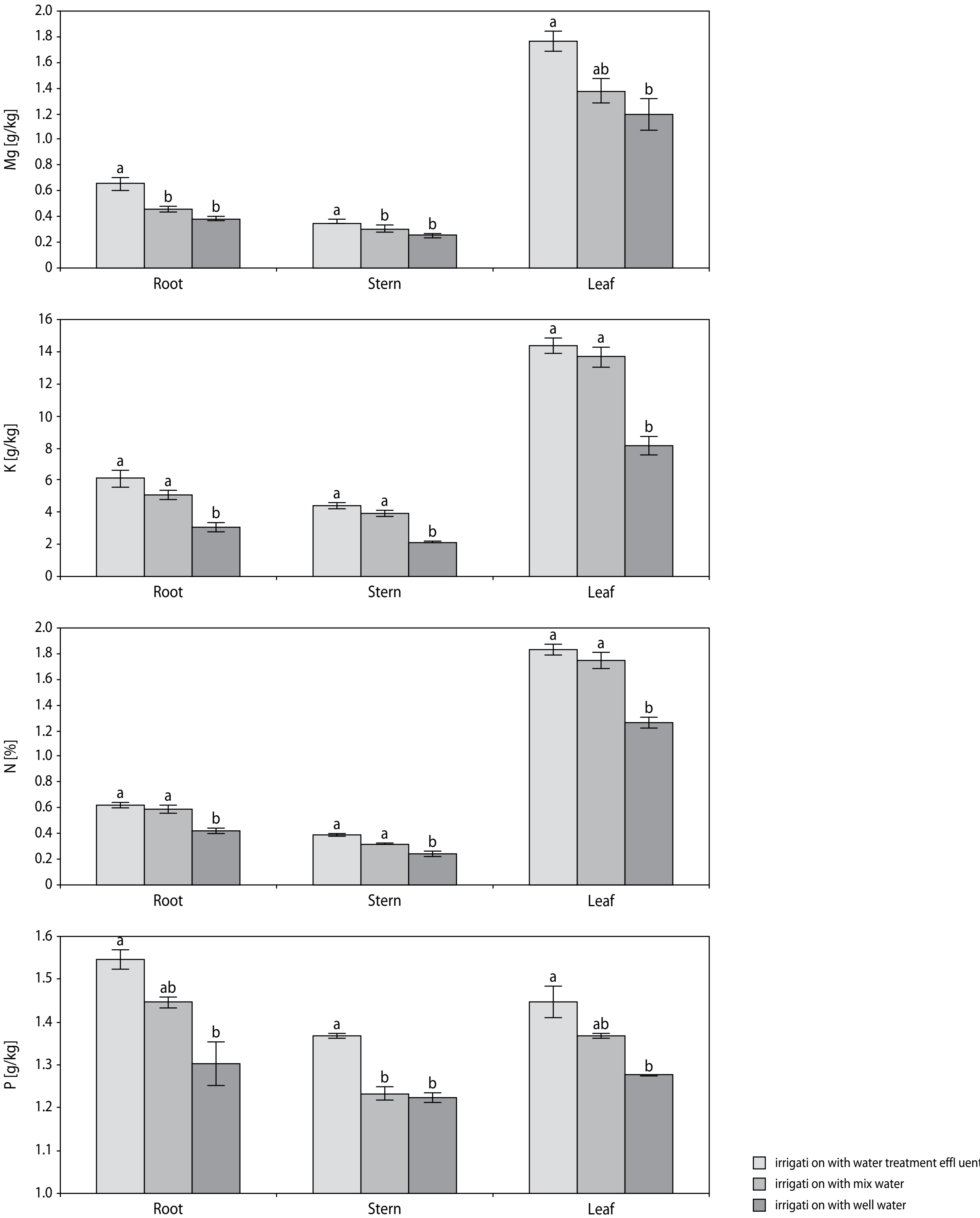

Fig. 2. Comparison of nutrient contents in differently irrigated *Fraxinus excelsior* seedlings. Different superscripts indicate significant differences ($p < 0.01$)

in soil irrigated with fresh or rainfall water. Nyamangara and Mezezewa (2000) found that the concentration of K on the control treatment was decreased with soil depth and increased in soil surface. Mohammad and Mazahreh (2003) considered the variation in the chemical composition of the wastewater, which should account for the N, P and K content prior to determination of wastewater application rate. Other researchers found that wastewater irrigation increased soil N, P and K contents, while heavy metal levels tended to generally increase in soil with increasing number of years of irrigation (Vazquez-monitel et al. 1996; Jalali et al. 2007). A pot experiment on mahogany seedlings *Swietenia mahagoni* (L.) Jacq. was carried out by Hayssam et al. (2010) to compare the effect of sewage irrigation (primary and secondary effluent) with that of tap water treatments on soil chemical properties The effects of sewage effluent on treated soil were more pronounced when treatments were applied for a long period of time. The study of Singh et al. (2010) on *Acacia nilotica* L, *Dalbergia sissoo* L. and *Eucalyptus camaldulensis* Dehnh. seedlings showed that the application of municipal effluent increased mineral concentration in soil. Thus, planting tree seedlings for ecological amelioration could help controlling land degradation and also enhance aesthetic environmental benefits.

Growth of seedlings

The application of water treatment effluent positively influenced the growth and production of *Platanus orientalis* L. The authors stated that various species had different reflections to irrigation with effluent. Treatment of *Eucalyptus grandis* Hill and Maiden with municipal effluent resulted in doubled tree growth rate when compared to *E. grandis* trees grown in a rainfed site for four years (Stewart et al. 1990). Height and diameter growth in seven tree species that were irrigated with municipal effluent for four years had significant difference (Hopmans et al. 1990). The study of Qgbonnaya and Kinako (1993) also suggested that *Eucalyptus globules* Labill. seedlings supplied with optimal amounts of water and nutrients or sewage water had greater growth rate than non-irrigated, unfertilized control seedlings. Similar results were reported by Guo and Sims (2000) who surveyed the effects of irrigating with meat works effluent on biomass production of *E. globules* seedlings and revealed that the use of meat works effluent increased the leaf area as well as biomass production.

Industrial saline wastewater had the same effect on the growth of trees, shrubs and herbs that well water (Gerharta et al. 2006). In this study, municipal effluent irrigation resulted in stimulation of tree growth and biomass production. Greater growth and biomass production of the trees irrigated with municipal effluent may be due to sufficient availability of water and essential elements (Guo et al. 2006). Ostos et al. (2007) reported similar results on *Pistacia lentiscus* Mastic. The authors observed that faster tree growth occured in the areas irrigated with effluent. They attributed growth increase to organic matter and macro- and micronutrient concentrations in wastewater applied. Effluent contains considerable amount of nitrates, phosphates and potassium which are considered essential nutrients for improving plant growth and soil fertility. Irrigation with water treatment effluent and nutrients provided with effluent application can be attributed to increase of growth and production of *F. excelsior* L.

Zhang et al. (2010) investigated the removal efficiency of nutrients from wastewater by the mangrove *Sonneratia apetala* Buch-Ham in a simulated wetland and showed that the amount of total mangrove biomass increased when the concentration of wastewater was higher. A pot experiment was conducted to study the effect of sewage irrigation treatments (primary and secondary effluent) compared with tap water on the growth of mahogany seedling *S. mahagoni* (L.) Jacq. The effects of sewage effluent on growth parameters were more pronounced as water treatments were used for long period (Hayssam et al., 2010). Bald cypress *Taxodium distichum* (L.) Rich. seedlings which were planted in effluent assimilation marsh experienced greater basal diameter growth compared to those planted in the control marsh, thus planting assimilation marshes with bald cypress seedlings can be an effective restoration tool for coastal Louisiana whereas wastewater treatment wetlands may offer an effective tool for restoring coastal bald cypress – water tupelo *Nyssa aquatic* L. swamps in Louisiana (Lundberg et al. 2011).

Seedling mineral parameters

The nutrient concentration and uptake in *F. excelsior* may arise due to water and nutrient supply. Plant essential nutrient N, P, K and Mg were higher in plants grown in soils irrigated with water treatment effluent. Plants elements absorption were not only impressionable from their concentrations in soil, their forms and soil physicochemical attributes, but also plants nutritions, the stage of plant growth and many other factors (Torabian and Mahjouri 2002). Movahedian et al. (2002) reported that different plantspecies have different abilities in elements absorption from the soil. On the other hand, Sing and Sharma (1982) stated that element concentration in plant parts depended on the amount of elements in effluent. Nitrogen concentration in plant shoots was reported to be higher when grown with wastewater (Day et al. 1979). It was found that N recovery in plants with wastewater was higher than the N recovery in plant material grown with well water. These results were attributed to significant increase in soil nitrogen with municipal effluent irrigation when compared with the control. Other researchers reported an increase in P, K and Mg uptake by plants irrigated with treated wastewater (Papadopoulos and Stylianou 1988; Mohammad and Mazahreh 2003; Singh and Bhati 2005; Herpin et al. 2007).

Zhang et al. (2010) investigated the removal efficiency of nutrients and heavy metals from wastewater by the mangrove *S. apetala* in a simulated wetland and suggested that mangrove wetlands with *S. apetala* species had great potential for the removal of nutrients in coastal areas. In the similar study a pot experiment was investigated to show the effect of sewage irrigation treatments (primary and secondary effluent) compared with tap water on the chemical constituents of mahogany seedling *S. mahagoni*. The effects of sewage effluent on elements content in plant parts were more pronounced as water treatments were used for long period (Hayssam et al., 2010). The study of Singh et al. (2010) on *A. nilotica*, *D. sissoo* and *E. camaldulensis* seedling showed that application of municipal effluent increased minerals concentration in seedling, but nutrient utilization efficiency was highest in *A. nilotica* for K, Ca, Mg and Na and *D. issoo* for N and P. Thus, planting tree seedling under ecological amelioration could in this way help in controlling land degradation and enhancing biomass and aesthetic benefits.

Conclusion

Soil and tree seedling quality parameters are significantly affected when 6-month irrigated with water treatment effluent. This is mainly determined by management of effluent irrigation and its composition. However, continuous irrigation with water treatment effluent may lead to accumulation of salts and plant nutrients in soil beyond crop tolerance levels. These concerns should be essential components of any management of effluent irrigation. On the other hand, plant growth as well as soil fertility and productivity can be enhanced by properly managed water treatment effluent irrigation, through increasing a level of plant nutrients and soil organic matter. It can be concluded, based on the results obtained that proper management of water treatment effluent irrigation and periodic monitoring of soil fertility and quality parameters are required to ensure successful, safe and long-term reuse of effluent for irrigation. Ash seedlings irrigated with water treatment effluent showed optimum plant nutrient concentration. Moreover, in general, distribution of water treatment effluent for irrigation over large land areas causes minimal pollution hazard. It may be used as an optimal strategy for raising woodlot to supply fuel wood in vicinity of suburban areas.

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References

Abulroos S.A, Holah Sh.Sh., Badawy S.H. 1996. Background levels of some heavy metals in soil and corn in Egypt. *Egyptian Journal of Soil Science*, 36, 83–95.

Ali H.M, El-Mahrouk E.M., Hassan Fatma A., Khamis M.H. 2010. Growth, chemical compositions and soil properties of *Tipuana speciosa* irrigated with sewage effluent. The 25th Meeting of Saudi Biological Society, Nanotechnology in Life Sciences, Alasa City at King Faisal University.

Baddesha H.S., Cabbra R., Ghuman B.S. 1985. Change in soil chemical properties and plant nutrient content under Eucalyptus irrigated with sewage water. *Journal of the Indian Society of Soil Science*, 45, 385–362.

Day A.D., McFadyen J.A., Tucker T.C., Cluff C.B. 1979. Commercial production of wheat grain irrigated with municipal waste water and pupm water. *Journal of Environmental Quality*, 8, 3.

EL-Nennah M., EL-Kobbia T., Shehata A., EL-Gamal I. 1982. Effect of irrigation loamy sand soil by sewage effluents on its content of some nutrients and heavy metals. *Plant and Soil*, 65, 289–292.

EL-Sayed N.A.A. 2005. The impact of irrigation with treated wastewater effluent on soil bio-physico-chemical properties and on growth and heavy metals content of some fodder trees grown on calcareous soil. Ph.D. thesis, Fac. Agric., Tanta Univ.

Evenhuis B. 1976. Simplified methods for foliar analysis, Parts I-IIV, Internal, Report Royal Tropical Institute, Amsterdam.

Gerharta V.J., Kaneb R., Glenna 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. 2000. Effect of meatworks effluent irrigation on soil, tree biomass production and nutrient uptake in *Eucalyptus globulus* seedlings in growth cabinets. *Bioresource Technol*ogy, 72, 243–251.

Guo L.B., Sims R.E.H., Horne D.J. 2006**.** Biomass production and nutrient cycling in Eucalyptus short rotation energy forests in New Zealand. II. Litter fall and nutrient return. *Biomass Bioenergy*, 30, 393–404.

Hayssam M.A., EL-Mahrouk M., Hassan F.A., EL-Tarawy M.A. 2010. Usage of sewage effluent in irrigation of some woody tree seedlings. Part 3: *Swietenia mahagoni* (L.) Jacq. Saudi. *Journal of Biological Sciences*, In Press, Corrected Proof.

Herpin U., Gloaguen T.V., Fonseca A.F., Montes C.R., Mendonca F.C., Piveli R.P., Breulmann G., Forti M.C., Melti A.J. 2007. Chemical effects on the soil-plant system in a secondary treated wastewater irrigated coffee plantation. A pilot field study in Brazil. *Agricultural Water Management*, 89, 105–115.

Hopmans P., Stewart H.T.L., Flinn D.W., Hillman T.J. 1990. Growth, biomass production and nutrient accumulation by seven tree species irrigated with municipal effluent at Wodonga, Australia. *Forest Ecology and Management*, 30, 203– 211.

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

Jalali M., Merikhpour H., Kaledhonkar M.J., Van Der Zee S.E.A.T.M. 2007. Effect of wastewater irrigation on soil sodicity and nutrient leaching in calcareous soils. *Agricultural Water Manag*ement (In Press).

Lindsay W.L., Norvell W.A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*, 42, 421–428.

Lundberg C.J., Shaffer G.P., Wood W.B., Day J.W. Jr. 2011. Growth rates of baldcypress (*Taxodium distichum*) seedlings in a treated effluent assimilation marsh. *Ecological Engineering*, In Press, Corrected Proof.

Mancino C.F., Pepper I.L. 1992. Irrigation of turfgrass with secondary sewage effluent: Soil quality. *Argonomy Journal*, 84 (4), 650–654.

Mitra A., Gupta S.K. 1999. Effect of sewage water irrigation on essential plant nutrient and pollutant element status in vegetable growing area around Calcutta. *Journal of the Indian Society of Soil Sci*ence, 42, 35–69.

Mohammad M.J., Ayadi M. 2004. Forage yield and nutrient uptake as influenced by secondary treated wastewater. *Journal of Plant Nutrition*, 27 (2), 351–365.

Mohammad M.J., Mazahreh N. 2003. Changing in soil fertility parameters in response to irrigation of forage crops with secondary treated wastewater. *Communications in Soil Science and Plant Analysis*, 34 (9/10), 1281–1294.

Monnett G.T., Reneau R.B., Hagedorn C. 1996. Evaluation of spray irrigation for on-site wastewater treatment and disposal on marginal soils. *Water Environment Research*, 68 (1), 11–18.

Movahedian H., Bina B., Vahid Dastjerdi M. 2002. Study on heavy metals accumulation in soil and crops irrigated with Isfahan wastewater treatment plant effluent. *Journal of Research in Medical Sciences,* 2, 117–122.

Murphy J., Riley J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31–36.

Naghshinehpour B. 1998. Application of effluent in agriculture productions and soil rehabilitation. First congress on the programming and policy in infrastructural matter (water and soil). Ministry of Agriculture.

Neilson G.H., Stevenson D.S., Fitzpatrick J.J., Brownlee C.H. 1989. Nutrition and yield of young apple trees irrigated with municipal waste water. *Journal of the American Society for Horticultural Science*, 114, 377–383.

Nyamangara J., Mzezewa J. 2000. Effect of long-term application of sewage sludge to a grass pasture on organic carbon and nutrients of a clay soil in Zimbabwe. *Nutrient Cycling in Agroecosystems*, 59, 13–18.

OMA 1990. Official Methods of Analysis. 15th Edn. Association of official Analytical Chemists, Arlington, Virginia, USA.

Ostos J.C., Lopez-Garrido R., Murillo J.M., Lopez R. 2007. Substitution of peat for municipal solid waste-and sewage sludge-based composts in nursery growing media: Effects on growth and nutrition of the native shrub *Pistacia Lentiscus L. Bioresource Technology* (In Press).

Papadopoulos I., Stylianou Y. 1988. Trickle irrigation of cotton with treated effluent. *Journal of Environmental Quality*, 17, 4.

Qgbonnaya C.I., Kinako P.D.S. 1993. Growth and mineral nutrition of *Gmelina arboria* seedlings fertilized with four sources of nitrogen on a latolic soil. *Tree Physiology*, 12, 294–300.

Salem M.M., El-Amir S., Abdel-Aziz S.M., Kandil M.F., Mansour S.F. 2000. Effect of irrigation with sewage water on some chemical characteristics of soils and plant. *Egyptian Journal of Soil Science*, 40, 49–59.

Sebastiani L., Scebba F., Tognetti R. 2004. Heavy metal accumulation and growth responses in poplar clones eridano (*Populus deltoides* × *maximowiczii*) and I–214 (*P.* × *euramerilana*) exposed to industrial waste. *Environ. Exp. Bot.*, 52, 79–88.

Sing S., Sharma H.C. 1982. Effect of profile moisture and nitrogen levels on yield and oil content by Raya (*Brassica juncea* L. Czen). *Haryana Agricultural University Journal of Research*, 12, 486–494.

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

Singh G., Bhati M., Rathod T. 2010. Use of tree seedlings for the phytoremediation of a municipal effluent used in dry areas of north-western India: Plant growth and nutrient uptake. *Ecological Engineering*, 36, 1299–1306.

Stewart H.T.L., Hopmans P., Flinn D.W., Hillman T.J. 1990. Nutrient accumulation in trees and soil following irrigation with municipal effluent in Australia. *Environmental Pollution*, 63, 155–177.

Tabatabaei M. 1998. Sustainability in irrigation designs with wastewater. *Journal of Water and Environment*, 31, 28–35.

Tajrishi M. 1998. New and comprehensive outlook to the problem of municipal effluent of Tehran. *Journal of Water and Effluent*, 28, 16–30.

Torabian A., Hashemi F. 1999. Irrigation of green space with treated wastewater of Tehran. *Journal of Water and Effluent*, 29, 31–36.

Torabian A., Mahjouri M. 2002. Accumulation of heavy metals in vegetables in south of Tehran following irrigation with municipal effluent. *Soil and Water Science*, 16, 189–196.

Vazquezmontiel O., Horan N.J., Mara D.D. 1996. Managemnt of domestic wastewater for reuse in irrigation. *Water Science and Techno*logy, 33 (10/11), 355–362.

Walker C., Lin H.S. 2007. Soil property changes after four decades of wastewater irrigation: A landscape perspective. *Catena*, 9, 1–12.

Walker C. 2006. Enhanced techniques for determining changes to soils receiving wastewater irrigation for over forty years. Ph.D Thesis, The Pennsylvania State University, University Park, PA.

Zhang J.E., Liu J.L., Ouyang Y., Liao B.W., Zhao B.L. 2010. Removal of nutrients and heavy metals from wastewater with mangrove *Sonneratia apetala* Buch-Ham. *Ecological Engineering*, 36, 807–812.